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*REPORT OF SURVEY CONDUCTED AT*

**NASA MARSHALL**
**SPACE FLIGHT CENTER**
**HUNTSVILLE, AL**
*APRIL 1999*

# *Best Manufacturing Practices*

1998 Award Winner

INNOVATIONS IN AMERICAN GOVERNMENT

**BEST MANUFACTURING PRACTICES CENTER OF EXCELLENCE**
**College Park, Maryland**
**www.bmpcoe.org**

# Foreword

This report was produced by the Office of Naval Research's Best Manufacturing Practices (BMP) program, a unique industry and government cooperative technology transfer effort that improves the competitiveness of America's industrial base both here and abroad. Our main goal at BMP is to increase the quality, reliability, and maintainability of goods produced by American firms. The primary objective toward this goal is simple: to identify best practices, document them, and then encourage industry and government to share information about them.

The BMP program set out in 1985 to help businesses by identifying, researching, and promoting exceptional manufacturing practices, methods, and procedures in design, test, production, facilities, logistics, and management – all areas which are highlighted in the Department of Defense's 4245.7-M, *Transition from Development to Production* manual. By fostering the sharing of information across industry lines, BMP has become a resource in helping companies identify their weak areas and examine how other companies have improved similar situations. This sharing of ideas allows companies to learn from others' attempts and to avoid costly and time-consuming duplication.

BMP identifies and documents best practices by conducting in-depth, voluntary surveys such as this one at NASA Marshall Space Flight Center (MSFC), Huntsville, Alabama conducted during the week of April 26, 1999. Teams of BMP experts work hand-in-hand on-site with the company to examine existing practices, uncover best practices, and identify areas for even better practices.

The final survey report, which details the findings, is distributed electronically and in hard copy to thousands of representatives from industry, government, and academia throughout the U.S. and Canada – *so the knowledge can be shared.* BMP also distributes this information through several interactive services which include CD-ROMs, BMPnet, and a World Wide Web Home Page located on the Internet at http://www.bmpcoe.org. The actual exchange of detailed data is between companies at their discretion.

MSFC has a legacy of extraordinary advancements that help make the impossible become a reality. With its unique blend of knowledge and capabilities, the Center continues to be an innovative force behind many of NASA's breakthroughs. Among the best examples were MSFC's accomplishments in unsteady computational fluid dynamic analysis of turbines; rapid prototyping; plume induced environments; NASA/Air Force cost model; the Collaborative Engineering Center; and the X-Ray Calibration Facility.

The Best Manufacturing Practices program is committed to strengthening the U.S. industrial base. Survey findings in reports such as this one on MSFC expand BMP's contribution toward its goal of a stronger, more competitive, globally-minded, and environmentally-conscious American industrial program.

I encourage your participation and use of this unique resource.

Ernie Renner
*Director*, Best Manufacturing Practices

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# Section 1

## *Report Summary*

### *Background*

Years before the National Aeronautics and Space Administration (NASA) was established, a group of scientists and engineers known as the von Braun team became prominent in America's fledgling space program. During World War II, Dr. Wernher von Braun and his team developed the V-2 rocket for Germany. However, von Braun's real interest lay in developing rockets for space exploration. By June 1945, many of Germany's experts surrendered to Allied forces and were sent to the United States via Operation Paperclip. Eventually, a group (including von Braun) ended up at the U.S. Army's Redstone Arsenal in Huntsville, Alabama. Between 1950 and 1956, von Braun led the team at the Development Operations Division of the Army Ballistic Missile Agency (ABMA) in designing the Redstone and Jupiter-C rockets. Still dreaming of space exploration, von Braun published articles (e.g., concepts of space stations, lunar landing vehicles) in *Collier's* and worked with Disney Studios (e.g., space exploration films for television) in hopes of bringing about greater public interest in a space program. On January 31, 1958, ABMA used a Jupiter-C rocket to launch Explorer 1, America's first orbiting satellite. This event signaled the start of the U.S. space program. Two years later, NASA established the Marshall Space Flight Center (MSFC) and named von Braun as its first Center Director.

Originally organized by obtaining buildings, land, space projects, and personnel from ABMA, MSFC was officially dedicated on September 8, 1960 by President Dwight D. Eisenhower. This NASA facility was named in honor of General George C. Marshall, the acclaimed Army Chief of Staff, Secretary of State, and Nobel Prize winner who developed the Marshall Plan for rebuilding Europe after World War II. Not long after MSFC opened, the United States sent its first astronaut, Alan Shepard, into space onboard a Mercury-Redstone vehicle. Visitors can see the historic Redstone Test Stand where the rocket used for this suborbital flight was tested. In addition, the Center built the Saturn V rockets that launched Apollo astronauts to the moon. Test firing of the Saturn rockets was an unparalleled spectacle of sight and sound in the Land of the Earth Shakers. The event was described as total flame, total sound, and total power. Often the noise was heard in a radius in excess of 100 miles. The Saturn V Dynamic Test Stand is also designated as a national historic landmark at the Center. Throughout its history, MSFC participated in many significant space projects including the Redstone, Juno, and Saturn rockets; Mercury, Gemini, and Apollo programs; Lunar Roving Vehicles; Apollo-Soyuz mission; Skylab space station; Redshift Experiment; Space Shuttle program; and the Hubble Space Telescope.

Today, MSFC is NASA's Center of Excellence for Space Propulsion, and specializes in three mission areas: (1) Space Transportation Systems Development, (2) Microgravity, and (3) Optics Manufacturing Technology. In addition, MSFC provides its customers with high quality products and services; actively participates in the local community; adapts to change through innovative thinking and flexibility; and enhances and sustains its highly skilled, diverse, and motivated workforce. The Center employed 2,715 personnel, encompassed 1,841 acres, and had a fiscal budget of $2.33 billion in FY98. MSFC is a world leader in access to space and the use of space for research and development to benefit humanity. Among the best practices documented were MSFC's unsteady computational fluid dynamic analysis of turbines; rapid prototyping; plume induced environments; NASA/Air Force cost model; the Collaborative Engineering Center; and the X-Ray Calibration Facility.

MSFC has a legacy of extraordinary advancements that help make the impossible become a reality. With its unique blend of knowledge and capabilities, the Center continues to be an innovative force behind many of NASA's breakthroughs. In addition, MSFC partners with local businesses and academia; pioneers environmental and safety efforts; and fosters technology transfer. Current and future programs involve advanced space propulsion systems; chemical engines; automated rendezvous and capture capabilities; reusable launch vehicles; tethersystems; the Chandra X-Ray Observatory; and the International Space Station. The BMP survey team considers the following practices to be among the best in industry and government.

## *Best Practices*

The following best practices were documented at NASA MSFC:

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### Thermography Non-Destructive Evaluation — 14

Thermography is a non-destructive analysis technique used to create thermal images. In 1996, MSFC upgraded its imaging system by installing a more sensitive camera capable of resolving temperature differences down to 0.025° C and collecting images in a digital format. Other new capabilities include scanning the entire picture frame at one time; automating and synchronizing a predictable heating source with data acquisition; and easily storing and enhancing the resulting images.

### Unsteady Data Reduction and Analysis System — 15

Unsteady data must undergo significant processing before meaningful results can be obtained, which makes real-time analysis difficult. To speed up the process, MSFC implemented an Unsteady Data Reduction and Analysis system in May 1998 to handle data generated by cold flow testing of high flow-rate turbines and pumps.

### Vibration Development and Verification Testing — 15

By developing a method to correlate the accelerometer response of the unit under test with that of the shaker armature, MSFC successfully performed three-axis random vibration testing at extremely low, cryogenic temperatures. In addition, this method permits testing over a wider temperature range, allows the use of control points that may be inaccessible during testing, and avoids the need for specialized instrumentation.

### Composite Structures Manufacturing — 16

MSFC has a long and rich history as NASA's leader in large space hardware manufacturing. Around 1983, the Center established the Productivity Enhancement Complex as a full-scale manufacturing environment which has evolved into nearly 50 dedicated research areas. The Complex offers outstanding resources, expertise, and capabilities to produce a wide range of shapes and sizes of composite components.

### Environmental Control and Life Support Systems — 16

The International Space Station is the next-generation vehicle, and will require regenerative life support systems to effectively remain in space. MSFC is designing and testing the space station's Environmental Control and Life Support Systems, which will control the regenerative systems for sustaining a crew. An extensive design and test program is currently underway, including the development of the Core Module Integration Facility which will test all life support components and subsystems.

### Marshall Convergent Coating — 18

During a launch, the space shuttle's solid rocket boosters are exposed to extreme heat generated by wind resistance and engine exhaust. In Fall 1993, MSFC teamed with United Technologies' USBI to develop an environmentally friendly protective coating. Using convergent spray technology, they atomized epoxy and filler materials to create an ablative insulation material called Marshall Convergent Coating-1.

### Rapid Prototyping — 18

MSFC is successfully using Rapid Prototyping technology to fabricate engineering concept models. More than just a 2-D drawing or printout, Rapid Prototyping models combine the benefits of conventional prototyping and automated fabrication processes to produce a physical 3-D model of the actual design concept. These models have faster turnaround times, and are less expensive to produce than conventionally machined models.

### Real-Time Expert Systems for Spacecraft Health Monitoring and Command — 19

Intelligent software applications offer a way to reduce labor requirements so long-term operations can be effectively managed. Through deployments, the Mission Operations Laboratory has already demonstrated the benefits of intelligent software systems for real-time telemetry monitoring and commanding. MSFC's integrated systems engineering approach enhances design knowledge capture and retention for all mission phases, and allows the development cycle to be accelerated.

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**Web-Based Data System Solutions** 26

MSFC's Engineering Systems Department developed a series of Web-Based Data System Solutions for information and document management applications. This arrangement enables the Center to establish a paperless environment in support of ISO-9001 certification, and provide immediate accessibility to information per NASA's faster, better, cheaper approach.

## *Information*

The following information items were documented at NASA MSFC:

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**Advanced Concept Research Facility** 29

MSFC's Advanced Concept Research Facility is in the process of developing many alternative propulsion systems for use in a space environment. Most of these methods are still in the development stage and will, if accomplished, redefine the limit of travel which is possible today. Some of the cutting edge technologies being studied include: Solar; Nuclear; Fusion; Pulsed Propulsion and Power; and Magnetohydrodynamic Propulsion.

**Gas Dynamic Mirror Fusion Propulsion Engine** 29

One of the most critical aspects for performing a manned mission to Mars will be the space vehicle's propulsion system. MSFC's Gas Dynamic Mirror system is an example of a magnetic mirror-based fusion propulsion system. The Center maintains this system in steady state by injecting particles in the region of the homogeneous magnetic field to effectively balance the plasma loss through the mirrors.

**High Strength Aluminum Casting Alloy for High Temperature Applications** 30

In 1995, MSFC's metallurgists began working with Ford under a Space Act Agreement to develop a new, castable aluminum alloy that had a 30% improvement in tensile strength during operation in the required temperature range. The result was an aluminum-silicon alloy that meets or exceeds all original automotive criteria.

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**Marshall Electromagnetic Compatibility Design and Interference Control Handbook** 31

In 1995, MSFC developed the Marshall Electromagnetic Compatibility Design and Interference Control handbook to help electrical engineers use practical information in designing for the mitigation of electromagnetic interference. The handbook features guidelines, design techniques, practical measurements and prediction techniques, and practical retrofit fixes.

**Quantitative Risk Assessment System** 31

Probabilistic risk assessment is a method used to calculate an overall system risk by combining high level event probability distributions with probability distributions from each lower level item or process. MSFC uses the Quantitative Risk Assessment System to assess the reliability of the space shuttle and its major components; help perform trade-off evaluations; rank space shuttle failure modes; perform sensitivity analysis; assist in other analysis efforts; and evaluate proposed space shuttle upgrades (e.g., propulsion element).

**Solar Thermal Propulsion** 32

In the distant future, low cost propulsion will be needed for interplanetary travel and unmanned exploration. NASA foresees Solar Thermal Propulsion as a way to boost future payloads from a low earth orbit to a geosynchronous earth or higher orbit. MSFC's Solar Thermal Facility has already built the heliostat mirror, concentrator, quartz-windowed vacuum test chamber, absorber/thruster, and gaseous hydrogen plumbing.

**Army/NASA Virtual Innovations Laboratory** 32

MSFC's Engineering Systems Department, in conjunction with the U.S. Army's Redstone Arsenal, has developed the Army/NASA Virtual Innovations Laboratory. This laboratory develops effective human-interface-to-hardware designs by combining human modeling and analysis tools with virtual reality technologies.

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### Cryogenic Bearing Testing 33

Cryogenic bearing testing requires special requirements such as bearing test rigs to duplicate cryogenic turbopump conditions, and computer modeling codes to design special bearings. In the early 1980s, MSFC formed a multi-discipline team consisting of experts in tribology, design, test, materials, and fabrication to initiate a Bearing Test program. The team fostered many advancements such as improved bearing materials and liquid hydrogen testing capability.

### Integrated Space Station Electromagnetic Compatibility Analysis System 33

Six different international partners are designing and building major elements of the International Space Station. To ensure compatibility, MSFC developed the Integrated Space Station Electromagnetic Compatibility Analysis System. This integrated database system keeps track of electromagnetic compatibility between devices and systems on the space station, and enables engineers to evaluate the effects of electromagnetic interference on flight systems.

### Long Term Vacuum Testing of Lubricants 33

Lubricants used for space applications must be able to operate in a vacuum environment. To determine which ones are compatible for NASA missions, MSFC performs long term vacuum testing of lubricants, typically over a one-year period.

### Nuclear Fuel Element Simulation 34

MSFC is currently testing various forms of alternative propulsion methods. One such method is the Heatpipe Bimodal System, designed for nuclear thermal propulsion. The Center's objective is to fabricate and electrically test a module in order to determine its design limits and operational characteristics. Several modules will then be grouped together in a quarter core arrangement to investigate the interactions between the modules under various operational and fault modes.

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### Optical Plume Anomaly Detection 34

The Optical Plume Anomaly Detection is a system that analyzes and characterizes emitted spectrum from rocket plumes by monitoring the ultraviolet, visible, and near-infrared regions of the spectrum. Through the detection of metals in the exhaust plume, information relative to the degradation of hardware can be gathered and used for readiness and maintenance decisions.

### Orbital Atomic Oxygen Simulation Facilities 35

MSFC has developed and implemented orbital atomic oxygen simulation facilities based on the physical characteristics of a low earth orbit environment. This capability is used to determine the long term exposure characteristics of objects launched into space.

### Space Environmental Effects Testing Capabilities 35

MSFC has established the Combined Environmental Effects Test-Cell 3, a space environmental effects testing facility used to simulate combined space environments. This facility enables the Center to test, evaluate, and qualify materials for use on external surfaces in space.

### Telemetry Processing Systems 36

MSFC's Huntsville Operations Support Center manages and processes telemetry data for payloads such as real-time operations of the International Space Station. The Support Center is comprised of four systems: Payload Planning System; Payload Data Services System; Enhanced Huntsville Operations Support Center System; and Enhanced Mission Communications System.

### Friction Stir Welding 37

MSFC is currently conducting studies to determine the feasibility of using friction stir welding to manufacture hydrogen fuel tanks and as a replacement process for situations where current material join methods are mechanically inferior. The Center has already demonstrated the commercial use of friction stir welding for manufacturing aluminum 5454 wheel rims.

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### Vacuum System Automation — 38

MSFC's Environmental Test Facility is currently implementing the Vacuum System Automation project. This project involves upgrading and automating the facility's 20 vacuum chambers. Automation will be controlled with Supervisory Control and Data Acquisition software, so operators can access the chambers via the Internet for data and via remote dial-ins for parameter adjustments.

### Metallurgical Diagnostics Facility — 38

Beginning in 1994, MSFC identified four areas in which to improve its Metallurgical Diagnostics Facility: (1) work request closure verification, (2) documentation and image storage and retrieval, (3) budget planning and justification, and (4) data access and distribution. Improvements in these areas have eased MSFC's transition to ISO-9000 certification and to the recently implemented NASA Full Cost Accounting requirements.

### Plating Research Facility — 38

MSFC's Plating Research Facility is currently developing a plating process which will allow multiple replicated optical mirrors to be produced from one mandrel. The developers have learned to define and control multiple plating parameters including temperature, current density, component placement in tanks, bath chemistry and consumption rate, shielding, and fluid flow.

### New Initiatives of NASA Acquisition Internet Service — 39

In an effort to continue improving NASA Acquisition Internet Service, MSFC has embarked on several enhancements including the Procurement Data Warehouse System and the Request For Quotes System. These initiatives represent the next phases of how NASA is improving its procurement process.

### Payload Safety Readiness Review Board — 39

In July 1996, MSFC created an internal Payload Safety Readiness Review Board to ensure the quality of its payload safety processes and products. Additionally, the Safety and Mission Assurance Office developed a Center Safety Readiness Review process to improve this aspect of work and provide a means of ensuring in-depth flight readiness of all payloads and experiments. Keys to the success of this process are a high level of attention by management and the use of a formalized dry-run approach.

### Project Light — 39

In 1996, MSFC implemented Project Light as a Center-wide program to bring about change and process improvement. The program employs a quality action team approach using Cross-Functional Employee Teams (providers and customers from multiple organizational levels) and an Executive Steering Committee (three center managers, four functional managers, one program manager, two employees).

### Strategic and Implementation Planning — 40

Enacted in 1993, the Government Performance and Results Act requires all federal agencies to develop strategic and performance plans which outline their goals and objectives in outcome-based terms. MSFC is complying with this act, and has implemented a strategic planning process that sets performance goals for the upcoming fiscal year and defines performance indicators to measure outcomes.

## *Point of Contact*

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# Section 2
# *Best Practices*

## *Design*

### Adaptive Optics Mirror Systems

The very large space telescopes under study at the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) involve large-diameter mirrors. Disadvantages of conventional monolithic designs included reliance on large, expensive, power-demanding electronics for future sensing and actuation; unnecessary risk of damaging the mirrors due to difficulty in handling them; and the need for large fabrication and test facilities. Floating point gate arrays are used for flexible, broad application, miniaturized electronics. Conventional labor-intensive grinding and polishing operations often induce unacceptably large stress fields in the material. To resolve these drawbacks, MSFC's Advanced Optics Development Group is developing mirror systems that use ultra lightweight replicated mirrors.

The redesigned mirror system has many improvements over its predecessor. Segmented mirrors now exist as hexagonal tiles with diameters of less than one meter, compared to the previous 1.5 to 3.5-meter monolith designs. These smaller mirrors feature thinner cross-sections, less mass, and easier, cost effective fabrication. MSFC's system also uses modular electronics with an extensible architecture for growth paths; a serial data loop originating at the master timing module; and symmetrical card and connector layouts. Modular electronics exist in seven, 36, and 91 segments with an application currently underway at a major observatory. Instead of using surface mount components, floating point gate arrays employ flexible and programmable devices (e.g., ROMs, PROMs). As a result, these arrays operate more efficiently and increase the bandwidth from nearly 0 Hertz (Hz) to more than 100 Hz. Replicated mirrors are now fashioned by depositing mass where needed, rather than by removing excess via mechanical means. This approach lowers internal stress fields, improves mirror figures, and provides high quality products at less than $20,000. Additional enhancements result from the electro-mechanical deposition on mandrel with sub-nanometer micro-roughness and diffraction-limited figure.

With these design changes, the Advanced Optics Development Group significantly revised optics mirror systems for space telescopes and gained valuable knowledge for future improvements. The Group determined that the optimum hexagon size is between seven centimeters and one meter; high quality test bed emulators become crucial during the development phase; new-generation floating point gate arrays continue to enhance the product design paradigm; and the tight radius of curvature specification exceeds the capability of commercial sources of replicated mirror segments.

### Collaborative Engineering Center

MSFC set up the Collaborative Engineering Center (CEC) as a way to improve quality and reduce the cost of its proposals and pre-projects. By using the CEC's engineering processes, the design team determines the composition and cost of a space mission's proposal development.

The CEC's engineering process differs fundamentally from traditional aerospace design processes. Using CEC's networked tools and databases, the design team obtains the necessary supporting information to make immediate design decisions. Next, the team develops the conceptual mission design and associated costs during three-hour, team design sessions. A minimum of two sessions is required to design and cost a mission concept. Figure 2-1 shows how a baseline assessment (proven technology) is reduced in cost and advanced in technology by using a systematic process of technology insertions.

Since implementing CEC's capabilities, MSFC has significantly reduced the cycle time for early design concepts while achieving more design iterations and identifying lower cost systems. Many benefits from the concurrent engineering process are a result of using a standing design team — one team designs many missions. In FY98, this team completed 57 studies, thereby providing many opportunities for the team to work together through a well-honed process.

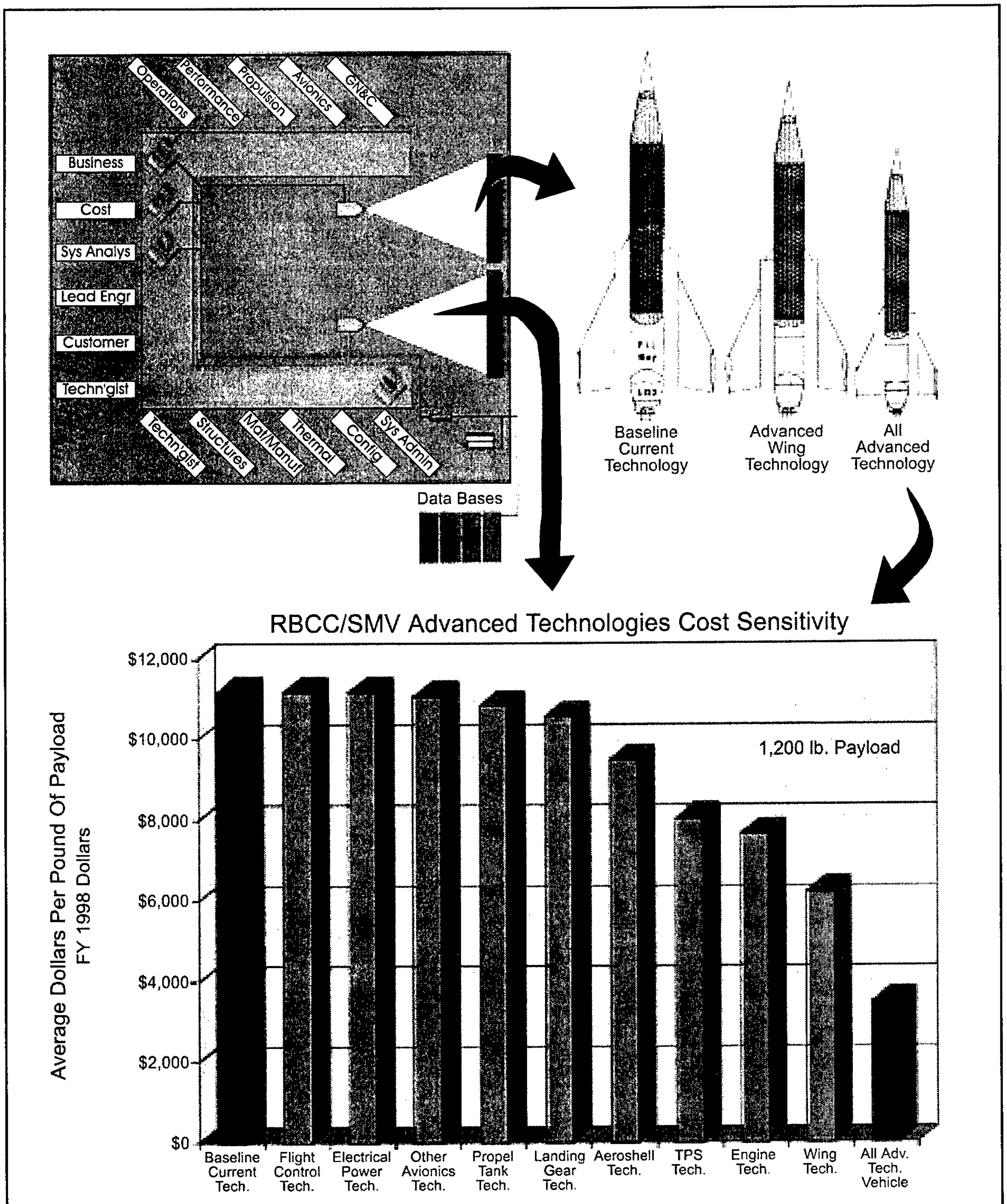



*Figure 2-1. Technology Assessment (Bantam) - Phase 1*

## Phased Array Mirror Extendible Large Aperture

The Phased Array Mirror Extendible Large Aperture (PAMELA) is the first telescope to have a fully-adaptive segmented mirror. This mirror consists of 36 hexagonal segments, each measuring seven centimeters across flats. Each mirror segment is tripod-mounted on three voice coil actuators which provide automatic tip, tilt, and piston adjustments of each segment relative to its neighbors. In 1993, MSFC acquired PAMELA from the Command Sciences Corporation in Tucson, Arizona, and determined that the telescope was functional but needed to be qualified.

MSFC decided to use PAMELA as a development test bed. To achieve this goal, the Center made numerous innovative improvements to the optical performance of the telescope. As received, some individual mirror segments exhibited peak-to-valley surface irregularities of up to 0.375 wave, as measured by a Wyco 6000 Interferometer. Consequently, MSFC's Optics Group removed all mirror segments and measured their radii of curvature. Eight segments were chosen to be refigured.

After reassembling the telescope, the Group discovered that actuator displacements as small as 0.005 inch could introduce one-wave, peak-to-valley, surface perturbations. Stress analyses of the mirror segments, as mounted on their substrates, were performed to verify that stresses during actuator movements were below yield or ultimate. The Group reasoned that since the segments were easily distorted, this characteristic could be used for flatness adjustment if a precision, repeatable method of adjustment could be devised. A 0.024-inch thick ring gasket was installed between the three actuators and the mirror segment substrate. This gasket acted as a stiff spring when the actuators were reinstalled, allowing precise tip and tilt adjustments at each actuator dependent on mounting screw torque. This adjustment capability reduced mirror segment flatness errors from 0.488 to 0.038 wave, approximately a 13:1 improvement.

The resonant frequency of the mirror segment, as mounted on its substrate and tripod-supported by the three voice coil actuators, was found to be in the 60 to 70 Hz range. This resonance presented a stability problem to the mirror segment positioning controller. A small, viscoelastic, multilayer, cantilever beam was constructed and added to each interface of the voice coil pistons with the mirror segment substrate. The resonance range of the mirror segment was effectively damped at 9.4%. In addition, this optimally damped system could be easily tuned and adjusted with the existing controller gain.

Additionally, the introduction of a Blue Line Quad Cell Wavefront Sensor calibration device permitted linear calibration to be achieved, with a noise floor improvement of 40 times better than the original Lateral Effect Diode Wavefront Sensor. Today, the image sensor spot intensity profile of the six-phased PAMELA has now been demonstrated as closely approaching theoretical reference accuracy.

## Unsteady Computational Fluid Dynamics Analysis of Turbines

MSFC's Fluid Dynamics Analysis Branch developed a process that utilizes Unsteady Computational Fluid Dynamic (CFD) analysis during the design cycle of a turbine to quantify, reduce, and/or manage flowfield unsteadiness. Until the recent integration of current processing power, this process typically took place after a turbine was already designed. The motivation for changing the process included: the ability to achieve better designs, lower costs, and an improved overall understanding of turbine design; the added complexities of supersonic flow from current and future turbines (e.g., Fastrac, Reusable Launch Vehicle); and the requirements for smaller, lightweight components which pushed turbines toward more compact, closely coupled designs magnifying the effects of flowfield unsteadiness.

The ability to accurately predict turbine flowfield unsteadiness in a timely manner is crucial to producing a design that meets a program's objectives. Flowfield unsteadiness is a major factor in turbine performance and durability. Unsteadiness is particularly important for several classes of turbines including supersonic, compact, counter rotor, high work designs, and designs using dense drive gases. Most modern rocket engine turbines fall within these classes.

The requirements of the Fastrac program drove the real-time technology of Unsteady CFD analysis in turbine engines. The objective was to demonstrate a reliable, low cost, turbopump-fed rocket engine using a reduced number of parts, a simpler design, a single stage with exit vanes, a supersonic flow, and commercial manufacturing techniques. To meet technical, cost, and schedule objectives of the Fastrac program, MSFC needed to run a series of Unsteady CFD analyses during the design phase on various areas including coupled and uncoupled nozzles, blade configurations, and exit guide vanes.

By using the Unsteady CFD analysis on the Fastrac program, MSFC completed its configuration calculations in approximately 14 weeks compared to the old method which would have taken about a year. Unsteady results supplied in a timely manner enable engineers to make real-time decisions that affect turbine performance. The ability to use Unsteady CFD analysis during the design phase results in an increased understanding of the turbine flow environment, produces a better design, and reduces the amount of rework during maintenance schedules.

## *Test*

### Computed Tomography Imaging

In 1988, MSFC purchased a state-of-the-art Computed Tomography (CT) scanner. Over the years, this device increasingly began to fail, averaging a 50% downtime by 1996. Since replacement parts became difficult to locate, engineers resorted to troubleshooting and replacing individual components on the memory boards. In addition, the customized computer operating system made the scanner difficult to master, the storage media (reel-to-reel) was bulky to maintain, and a replacement would cost several million dollars. A cost-effective alternative for MSFC was to upgrade its own system.

A CT scanner is used to produce an internal structural image by taking sequential, repetitive x-ray images along the length of an object. Each image represents an individual layer of the total picture. By combining these layers, a 3-D image of an object is produced. MSFC's primary use for its scanner is to analyze composite solid rocket nozzles. By using a 3-D image, engineers can easily view the internal structure of a rocket nozzle and identify potential anomalies, such as cracks or voids. MSFC's scanner is similar to those used in the medical industry for creating 3-D images of the human body, but operates at higher energy levels (420 keV tube with a 2-MeV linear accelerator) to image through much denser material.

MSFC modernized its CT scanner system by using commercial-off-the-shelf (COTS) imaging software and computer resources (e.g., dual processor motherboards, memory chips, video controllers). In addition, the Center also upgraded the operating system to UNIX; added special features such as a re-writeable CD-ROM drive and a backup tape drive; automated the diminish and measure capabilities for analyzing suspected anomalies; and set up a Tagged Image File Format for transporting images which are external to the system. The project took seven months and was completed in September 1997. The availability of the new system is currently at 95%.

The CT scanner was upgraded at a fraction of its replacement cost, approximately $225,000, which resulted in considerable cost savings for MSFC. Within the last 20 months, the system produced 8,500 images primarily for the Fastrac program. Prior to renovations, this scanner had produced only 13,300 images over a nine-year period. Future plans include upgrading the system to achieve higher resolution and constructing a smaller CT scanner from existing components.

### Docking and Berthing

NASA has successfully performed several docking/berthing maneuvers throughout the space program's history. In the early 1970s, MSFC created a six-degrees-of-freedom (6DOF) contact-dynamics simulation. This advanced technology process ensures the integrity and reliability of space hardware during a docking/berthing maneuver. Until recently, all 6DOF testing was performed at ambient temperature and atmospheric pressure. The development of the International Space Station (ISS) program, however, created a new dimension for testing. All remote fly-ins and docking/berthing of space hardware must be conducted in a thermally-controlled vacuum environment. In addition, the ISS Common Berthing Mechanism (CBM) requires testing to be performed under operational vacuum and thermal conditions.

To meet these requirements, MSFC adapted its V20 Thermal Vacuum Environmental Test Chamber to perform tests using 6DOF's operational capabilities:

- Positional tolerance of ±0.05 inch and ±0.10 degrees
- Motion range of ±5 degrees for roll, pitch, and yaw; ±6 inches for translation in the horizontal plane; and 24 inches for vertical travel
- Payload weight of 2,500 pounds

This one-of-a-kind test facility also provides visual cues and pilot-in-the-loop studies; analytical contact-dynamics simulations; real-time anomaly resolution for ISS berthing; pilot-in-the-loop proximity operation to dock/berth mechanism hardware; and contact-dynamics testing of 1:1 scale to dock/berth hardware under operational thermal and vacuum conditions.

Since utilizing the V20 facility for docking/berthing simulations, MSFC realized many benefits for the ISS

program. These include testing hardware under operational vacuum and thermal conditions; redesigning the alignment guides and latches; identifying mechanical interference problems; setting up functional testing of CBM; and determining operational constraints of CBM hardware. In addition, NASA pilots gain familiarization with all aspects of docking and berthing. The real-time anomaly resolution for ISS berthing will provide a safety net for missions throughout ISS's assembly.

## Electronic Shearography

The spaceflight industry is rapidly changing and introducing stronger and lighter composites into vehicle designs. As a result, MSFC's inspection teams needed a more flexible and portable system for detecting defects beneath insulation, paint, and laminated composites. Electronic shearography is a video inspection method used to detect debonds or separations in a test specimen. With the Center's state-of-the-art equipment, images can be collected in real time and viewed on a charge coupled device camera. In the past, traditional film photography was used to document and enhance material inspections. This method was time consuming and often involved cumbersome lasers and laborious manual processes.

In an electronic shearography system, a laser is passed through a beam expander which breaks up the beam and strikes the test specimen with divergent beams. The beams are then reflected back through a telephoto lens and gathered in a Michelson interferometer to provide variable image shear. The system records two images: (1) the reference image and (2) the sheared image. These images will interfere with one another, resulting in a recorded image of a laser speckle pattern indicative of the original test specimen's surface slope. The system can also detect surface imperfections by recording the slope of the surface. If a defect exists below the surface, it will eventually distort the surface profile as the deformation reaches the surface.

Electronic shearography has proven to be an effective means of inspecting a variety of materials for defects in multiple environments. Since implementing this system, MSFC's engineering staff can quickly adapt and integrate new inspection technologies. The system provides greater sensitivity, repeatable and uniform testing, and the ability to detect defects near inner surfaces of a closed-body structure such as fuel tanks. MSFC also uses electronic shearography to ensure product conformance and flight safety.

## Modal Test Facility

The Modal Test Facility at MSFC uses three primary modal test beds: (1) the Shuttle Payload Universal Modal Test Bed; (2) the ISS Rack Modal Test Bed; and (3) the Shuttle Spacelab Pallet Modal Test Bed. The purpose of each is to obtain dynamic characteristics of flight structures by using experimental modal testing methods. Modal test data enable engineers to determine the resonant frequency, damping, and mode-shape information about the tested structure. This information is used to verify finite element analysis (FEA) models of the flight vehicle with the test article mounted in place. This verification is necessary to assure that no unacceptable dynamic loads will be imposed on the flight vehicle by the structural resonance of articles being carried into space.

The Shuttle Payload Universal Modal Test Bed is capable of mounting the test article in a fixed-free configuration that represents the Shuttle trunnion mounting system. Typically, for a five-trunnion system with 30 degrees-of-freedom, seven degrees-of-freedom are fixed and the remainder are free relative to the fixed condition. The ISS Rack Modal Test Bed is capable of mounting the test article in a fixed configuration representing typical rack mounting. The Shuttle Spacelab Pallet Modal Test Bed is capable of mounting a Shuttle Payload attached to a Spacelab Pallet in a free-free test configuration. Up to 500 triaxial accelerometers (1,500 linear accelerometers) can be attached to the test article before applying up to six independent, benign, low-level, vibrational inputs over a frequency range of 0 Hz to 100 Hz. Engineers then measure the modal response of the test article, and can record up to 224 channels of data simultaneously. The recorded directional accelerometer information is used to compute the frequency response functions which, when curve-fitted, yield the desired modal parameters (e.g., resonant frequencies, damping coefficients, mode shapes) for verifying the FEA models.

MSFC's Modal Test Facility is considered a unique capability within the United States, and possibly the world. No other facility is known to be capable of performing modal testing on specimens that span up to 45 feet in length and weigh up to 40,000 pounds. The Facility's modal test data collecting, recording, and processing capabilities are considered unparallel.

## Plume Induced Environments

Plume induced environments are the heated areas on the launch vehicle's base regions caused by propulsive engine plumes. The ability to locate and characterize these hot spots is critical to ensuring a safe and successful mission. To monitor these areas, MSFC employs an integrated methodology that utilizes improved and integrated engineering codes; 3-D computational fluid dynamics; and modernized short duration convective and ground radiation test data. The previous method was a non-integrated system based on engineering and empirical techniques derived from 1960s and 1970s launch vehicles. The change in physical design of today's launch vehicles dictated the need for a new system which could accurately predict and monitor thermal hot spots.

Two primary heating phenomena are associated with plumes: (1) radiation heating where hot plume gases radiate at all altitudes, and (2) convection heating where hot plume gases are re-circulated around the base of the launch vehicle. Analysis of the heating environment will involve 20 to 200 vehicle body point measurements that are influenced by variables including engine gimbal angle, trajectory changes, and angle of attack. Figure 2-2 illustrates a typical body point distribution of the X-33 Reusable Launch Vehicle for plume heating calculations.

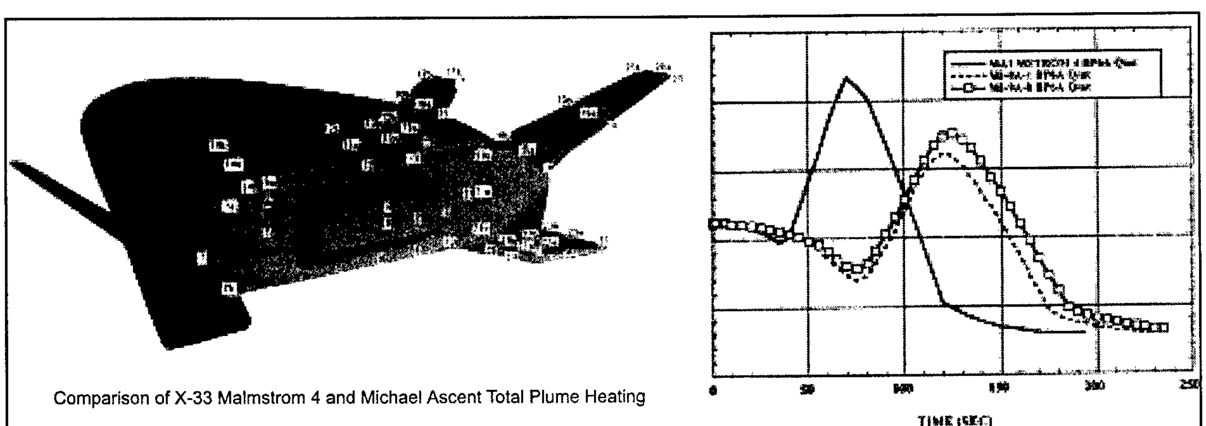
Since the 1960s, engineering codes have been a major area of development. Noted improvements include user input and output simplified by graphical user interfaces; artificial intelligence analogs added to mesh density selection and interpret result validity; integration of output data so that it automatically transforms into input for subsequent code; and acceptance of computational fluid dynamic plumes as input for radiation codes. Today's engineering codes involve band model gaseous radiation; nozzle and high altitude plume flowfields; reverse Monte Carlo radiation; the chemical equilibrium code; and the viscous shear layer of the plume.

The improvement of engineering codes and the use of faster, more powerful computers greatly aid plume environmental engineers in their work. As a result, MSFC reduced analysis time from weeks to hours, and significantly decreased testing costs from $6 million in the 1970s to $750,000 today.

## Thermography Non-Destructive Evaluation

Thermography is a non-destructive analysis technique where a material is thermally excited by a high-energy source (e.g., quartz lamps, high intensity flash). As the material cools, emitted infrared (IR) radiation can be analyzed with a thermal-imaging camera. Different materials absorb and release IR energy at different rates as heat propagates through, thereby creating a thermal image that can progressively penetrate deeper layers of the material. Thermography is particularly useful for examining composite materials because many are nearly invisible to x-rays. Delamination (voiding) inside the composite will create air-filled pockets that act as insulators. The area inside and around this insulated area will cool at a different rate than the remainder of the material, thus creating a slightly altered thermal image.

In the past, MSFC used analog methods to collect thermal images, and then stored them on VCR tapes.



Comparison of X-33 Malmstrom 4 and Michael Ascent Total Plume Heating

***Figure 2-2. Typical X-33 Body Point Distribution***

Heating was done through manual means. This approach had several limitations because the resulting image was affected by the scan rate of the camera, and the camera could only scan the image in a left-to-right, top-to-bottom fashion. Also, the temperature sensitivity of the camera was relatively low (less than 0.1° C), and post-processing of the analog image was limited. As a result, engineers had difficulty in enhancing images and identifying potential problems.

In 1996, MSFC upgraded its imaging system by installing a more sensitive camera capable of resolving temperature differences down to 0.025° C and collecting images in a digital format. Other new capabilities include scanning the entire picture frame at one time; automating and synchronizing a predictable heating source with data acquisition; and easily storing and enhancing the resulting images. The upgraded system can also quantify the size and severity of lamination and porosity anomalies, which aids in determining the size of a delamination (both interply unbonding and core/facesheet unbonding) and the porosity of the bonding material. This feature was achieved by developing defect standards. MSFC intentionally created delamination on coupons by inserting Teflon tape between bonding layers to simulate delamination, and used microballons and variations in vacuum bagging operations to simulate porosity during the fabrication process. The Center fabricated defects in various sizes, and took thermographic images of them. These images were then examined to determine the limitation of the technique, and to correlate the size of the defect on the image with the actual defect size.

By upgrading to a thermograpic, non-destructive evaluation process, MSFC can now analyze composite materials for potential delamination problems and quantify delamination/porosity within composite material. This process was also used to qualify the nose cone for the space shuttle's external fuel tank, as well as the space shuttle's main engine nozzle and the Bantam RP-1 fuel tank.

## Unsteady Data Reduction and Analysis System

Unsteady data is produced by many natural phenomena such as fluctuating pressure loads, flow instabilities, cavitation noise, and sonic booms. However, this type of data must undergo significant processing before meaningful results can be obtained, which makes real-time analysis difficult. To speed up the process, MSFC implemented an Unsteady Data Reduction and Analysis system in May 1998 to handle data generated by cold flow testing of high flow-rate turbines and pumps. In the past, the Center's analysis method involved collecting cold flow test data on analog tapes and sending them to another building for processing. Here, engineers converted the data from an analog to a digital format, loaded the information into a computer, and performed various analyses. Extra time was often spent importing data into various software packages to do data summary and graphing. Results took at least a full day or longer, which could create delays if the next test was dependent on the preceding test's results.

MSFC's Unsteady Data Reduction and Analysis system performs near-real-time analysis by using three systems: the Computer Aided Dynamic Data Monitoring and Analysis System (CADDMAS); the Operator Interactive Signal Processing System (OISPS); and the Coherent Phase Cavitation Monitoring System (CPCMS). CADDMAS is a parallel processor with 32 high frequency input channels that collects, stores, and performs real-time data analysis. OISPS performs conventional and advanced signal analysis on the data, and CPCMS determines the cavitation intensity.

Since implementing the Unsteady Data Reduction and Analysis system, MSFC realized faster test throughput, real-time identification of measurement problems, monitoring capabilities for anomalous results, and a user-friendly format for data. Although this system was designed for cold flow testing of high flow-rate turbines and pumps, the concept could be used on other tests where unsteady data is collected. Future plans include making the Unsteady Data Reduction and Analysis system able to handle system upgrades and be accessible by multiple code developers.

## Vibration Development and Verification Testing

NASA requirements called for the liquid hydrogen liquid level sensors for the space shuttle's super lightweight external tank to undergo three-axis random vibration testing at -423° F. During testing, the vibration levels also need to be monitored to ensure that the power spectral density stays within specified values. MSFC, however, discovered that the accelerometers used to measure the vibrations were unreliable at this extremely low, cryogenic temperature. Specifically, the accelerometers exhibited random DC shifts and high frequency spikes below -200° F. The Center concluded that it was not possible to chill the accelerometers to the required temperature and still get an accurate output.

MSFC first approached this issue by performing random vibration testing at room temperature and using a power spectral density, six decibels down from the required vibration level to guard against hardware damage. One accelerometer was mounted on the shaker armature and another on the unit under test (UUT). The resulting power spectral density levels were then measured. Next, MSFC derived the transmissibility (Q factor) between the armature and the UUT (and its mounting configuration) by examining the difference between the responses of the two accelerometers. Using the Q factor to adjust the input vibration levels of the shaker table, MSFC predicted that the output vibration levels would stay within parameters. To test the concept, MSFC performed random vibration testing at -200° F, the lowest temperature at which the accelerometers had proved reliable. Results confirmed that measurements inside the UUT agreed with the test criteria. Based on these results, MSFC concluded that its approach was viable and would have no appreciable effects as the temperature was further lowered. The UUT was then successfully isolated and chilled to -400°F ± 30°F.

By developing a method to correlate the accelerometer response of the UUT with that of the shaker armature, MSFC successfully performed three-axis random vibration testing at extremely low, cryogenic temperatures. In addition, this method permits testing over a wider temperature range, allows the use of control points that may be inaccessible during testing, and avoids the need for specialized instrumentation. This technique was successfully used on the anti-vortex baffle sensors as well as an X-33 valve, and was extended to acoustic testing.

## *Production*

### Composite Structures Manufacturing

MSFC has a long and rich history as NASA's leader in large space hardware manufacturing. Around 1983, the Center established the Productivity Enhancement Complex (PEC) as a full-scale manufacturing environment for developing and qualifying automated manufacturing processes and materials to meet future requirements and launch schedules. PEC began as a single research cell, and has evolved into nearly 50 dedicated research areas located throughout the Huntsville complex. Since the 1980s, the Center has also developed and produced various composite components for the space program, and is recognized as a national leader in this field. The Center offers outstanding resources, expertise, and capabilities to produce a wide range of shapes and sizes of composite components. Because of these attributes and its unique, cooperative working relationships with industry, MSFC is approached by many contractors to develop and demonstrate the feasibility of using composite components in their programs.

The industrial infrastructure for composite manufacturing, however, is slowly evolving throughout the Nation due to the high costs and risks associated with qualifying new materials for spaceflight. This situation, along with a small market for large composite components, have caused MSFC to become even more self-sufficient in this field. The continued investment in composite materials technologies at MSFC is essential, if new and advanced materials are to be utilized confidently in the next-generation space vehicle systems. NASA has already set goals to reduce costs by at least an order of magnitude. The newly developed Fastrac engine is an example of this cost reducing effort. When put into production, this engine can be delivered for approximately one-tenth the cost of a comparable engine built using yesterday's practices and materials.

The need to find affordable and reliable access to space continues to be a vital requirement for NASA and industry so they can remain competitive in the world market. MSFC, with its unique capabilities in composite manufacturing, is devoted to the advancement of composite materials and processes. By maintaining its partnership with industry, the Center can continue to provide the technological breakthroughs necessary for the next-generation systems of space transportation, thus assuring the Nation's continued leadership position in space technologies.

### Environmental Control and Life Support Systems

One of MSFC's capabilities is developing and testing life support systems for manned space missions. Typical systems include oxygen for breathing; food storage; filtering canisters for removing contaminants within the vehicle; stored water for drinking and washing; collection/storage containers for urine; and collection/treatment/storage containers for solid waste. As the manned space program grew, requirements changed and new technologies were developed. Early missions such as Mercury, Gemini, and Apollo used expendable throwaway systems because of the

vehicles' weight constraints and short flight durations. Regenerative systems and techniques were also impractical due to size, weight, and cost. However, the Space Shuttle program introduced a new era for manned space missions. As flights became longer in duration, systems were needed to support the regeneration of life support resources within the space vehicle. The continued use of expendables for these systems became too costly in terms of logistical support.

ISS is the next-generation vehicle, and will require regenerative life support systems to effectively remain in space. The design concept of the space station includes separate modules, airlocks, and nodes which are docked and assembled together to form a large pressurized enclosure. This enclosure must be capable of supporting manned operations for indefinite periods of time. Provisions (Figure 2-3) for sustaining a crew on ISS will be controlled by the space station's Environmental Control and Life Support Systems (ECLSS). NASA has delegated the responsibility of designing and testing ECLSS to MSFC. To support this assignment, an extensive design and test program is underway, including the development of the Core Module Integration Facility (CMIF) which will test ECLSS and its subsystems:

- Water Reclamation System — Has undergone analysis since 1990 with extensive testing and a continuous, 146-day cycle of operation.
- Vapor Compression Distillation Unit—Designed to process urine, has completed life testing requirements, and is now being used as a development unit to support a future spaceflight experiment.
- Biofilm Test — Determines if buildups are occurring by circulating clean and dirty water through onboard plumbing components.
- Internal Thermal Control System — Simulates the temperature and humidity control system of the space station, and is used to test fans, blowers, pumps, heat exchangers, etc.

The CMIF also contains the Common Module Simulator which is the same shape and diameter as the ISS core module. This unit contains all services (e.g., water, electrical, gas) needed to operate the various subsystems independently or as an integrated system. A new addition to the CMIF is a Habitation Module Simulator which is currently being outfitted to support ISS-sustaining engineering efforts. A complete set of ECLSS hardware will be installed in this simulator, so parallel operations can be performed with ISS operations to respond quickly to any on-orbit situation that might occur.

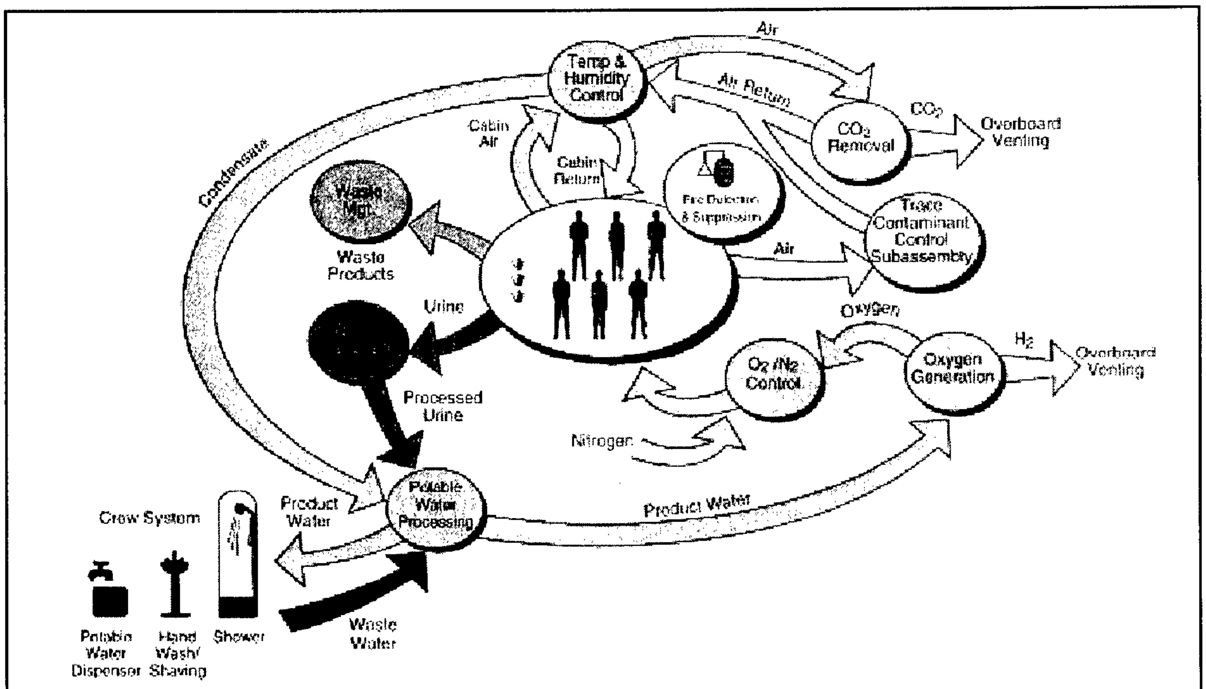



*Figure 2-3. Space Station Regenerative ECLSS Flow Diagram*

## Marshall Convergent Coating

During a launch, the space shuttle's solid rocket boosters (SRBs) are exposed to extreme heat generated by wind resistance and engine exhaust. In the mid-1980s, MSFC developed Marshall Sprayable Ablator-2 (MSA-2) as an ablative insulation material to protect the SRBs' forward assembly, systems tunnel covers, and aft skirt. During the MSA-2 process, nine ingredients are mixed with the adhesive and then applied to the desired area. Although effective, MSA-2 had many drawbacks. Each batch was costly and had a five-hour pot life. The application process was often interrupted which ruined some or all of a batch. The tensile strength of MSA-2 was difficult to regulate, and the material tended to come off the SRBs during the flight and especially at splashdown. The cost of investigating this anomaly added to the expense of using this insulation material. In addition, MSA-2 contained two chlorinated hydrocarbon solvents which were harmful to the environment.

The Space Act Agreement fosters the transfer of laboratory technology to real-world applications. In Fall 1993, MSFC teamed with United Technologies' USBI to investigate an alternative to MSA-2. Using convergent spray technology (CST), they atomized epoxy and filler materials to create an ablative insulation material called Marshall Convergent Coating-1 (MCC-1). This environmentally friendly coating is superior to MSA-2, and consists of 8% hollow spherical glass, 9% cork, and 83% two-part epoxy by weight. During the MCC-1 process, materials are mixed at the point of release from a specialized spray gun at the time of application. This solventless approach prevents interruptions from ruining a pre-made batch. The first SRB flight hardware sprayed with MCC-1 was a left-hand skirt for the Space Shuttle Atlantis (STS-79). The excellent performance during this September 1996 mission led to the full implementation of MCC-1 on all subsequent flights. Virtually no missing MCC-1 has been noted during the post-flight inspections of recovered SRBs.

Besides the SRBs, MCC-1 was used on the U.S. Air Force's Titan IV payload fairing trisectors and Boeing's Sea Launch, and has been selected for Boeing's Delta IV. There is potential to qualify MCC-1 for multi-flight use on the SRBs and to determine if CST can be used on the space shuttle's external tank as well as other SRB applications. Tested spin-offs of CST include acrylic filled with recycled rubber for roof surfaces on industrial buildings, and epoxy filled with abrasive flint as a skid-resistant coating for the road surfaces of the Bankhead Tunnel and a highway bridge on Interstate 65 in Alabama.

## Rapid Prototyping

MSFC is successfully using Rapid Prototyping (RP) technology to fabricate engineering concept models. More than just a 2-D drawing or printout, RP models combine the benefits of conventional prototyping and automated fabrication processes to produce a physical 3-D model of the actual design concept. These models have faster turnaround times and are less expensive to produce than conventionally machined models. Traditionally, solid models were created by using commonplace methods such as hand carving, manual machining, and/or the use of computer numerical control machine tools. Though successful, these methods are labor intense and require more time and skill than RP techniques. Models that usually took days or weeks to produce are now being completed in a few hours. In addition, the design engineer gets to see, hold, and examine the concept part much earlier in the design stages, thereby reducing costly rework of mating parts and assemblies due to design changes.

Since implementing RP technology, MSFC has immediately realized many benefits. One example involves investment casting patterns for three engine chambers. After the Center fabricates these patterns, an on-site contractor uses them to produce an Inconel 718 casting for each engine chamber. By using RP techniques, the fabricated patterns and castings cost about $3,500 each. MSFC estimates the cost at $30,000 each, if done using forged and machined parts. RP techniques enabled these products to be delivered and instrumented for hot-fire testing within four weeks, compared to 16 weeks using conventional methods. The overall savings on this project alone amounts to $79,500.

RP technology significantly reduces the cost and time to develop solid models and evaluate their form, fit, and performance prior to manufacturing the finished part. With MSFC's unique RP capabilities, the need for mock-ups and other intermediate steps (required to produce flight quality products) are being phased out as new materials are developed and larger size parts become more feasible to produce.

## Real-Time Expert Systems for Spacecraft Health Monitoring and Command

NASA realizes that its current approach to payload operations will be significantly changed because of continuing fiscal pressures. Since 1994, MSFC has funded the development of intelligent software applications for payload ground operations. These applications offer a way to reduce labor requirements so long-term operations, like ISS, can be effectively managed. Through deployments, the Mission Operations Laboratory (MOL) has already demonstrated the benefits of intelligent software systems for real-time telemetry monitoring and commanding. Seven test sets have flown on missions throughout 1998, and will culminate in a major development project to provide real-time command and control of scientific experiments (Express Racks). This project is slated to begin with ISS launch 6A in the second quarter of 2000.

G2 is the technology that enables object-oriented development of software applications, so MSFC can create intelligent control and diagnostic monitoring systems in a time-critical environment. This technology operates on Unix workstations and Windows NT PCs, and incorporates COTS software and an Optimized Advanced System Integration and Simulation (OASIS) programming shell. MSFC uses G2 across its program lifecycles, and integrates lifecycle data into this tool as libraries (Conceptual; Requirements; Design; Fabrication and Test; Training and Operations). This Common Lifecycle Toolset features sub-elements and reusable software steps which will evolve into the operational fidelity phase (optimal level of certainty) for life-critical decisions. G2's operator interface is done through text language and simulation technology. Because of the interface's flexibility and intuitiveness, no extensive knowledge of programming is required. Inference knowledge and generic object libraries, combined with OASIS, create several advantages for efficiencies and project costs related to programming.

During mission operations, a real-time expert system provides schematic-based telemetry monitoring, data trending, expected state monitoring, malfunction procedure execution, and high/low (analog) monitoring. Updated once per second, the system displays operator messages via graphics and prioritizes faults by using color schemes. Ground control personnel can monitor the system via remote, through the MOL, or with routed messages (e.g., e-mail, pager) based on predetermined parameters. In addition, faults are quickly traced to the component level through point-and-click commands, which provides the engineer with additional minutes for resolving a problem.

MSFC's integrated systems engineering approach enhances design knowledge capture and retention for all mission phases, and allows the development cycle to be accelerated. By using G2, MOL reduced labor needs, promoted communications, and achieved a ten-fold increase in productivity. MSFC expects greater savings once the fault detection and control systems are implemented on ISS.

## Thermal Spray Coating and Forming Processes

Thermal spray coating and forming is a process where a coating thickness of 0.001 to over 0.750 inch is applied to a surface. In addition, this process can layer dissimilar coating materials so that their desired properties work together, such as in functional gradient coatings. A typical example is the coating of alumina on tungsten and molybdenum. Thermal spray coating and forming is applicable to many metallic and non-metallic substrates. The process may also be a suitable alternative to electro-plating and organic paints, especially if portability, high deposition rate, or environmental issues are important.

MSFC uses three thermal spray coating and forming processes:

- Vacuum Plasma Spray can apply exotic metals in thick layers, but is costly and is limited to vacuum chamber operations. In an inert environment, plasma is generated by ionizing gas via an internally conducted arc and accelerates the coating material through the plasma flame to the substrate.
- High-Velocity Oxyfuel Spray can apply many material types and is cost effective. This method has no coating thickness restrictions nor noise considerations. The supersonic gas velocity from a combustion process propels the powder. The powder then melts as it passes through the flame and is deposited on the workpiece surface. The intense kinetic energy results in a dense, well-adhered coating.
- Wire Arc Spray is the most cost-effective method for material applications. To apply the coating, this method melts two advancing wires through an electrical arc, then introduces a high velocity gas that propels the coating toward the substrate. Another strength of this method is the rapid prototyping of parts by coating a foam mandrel and subsequently washing out the foam, leaving a working prototype that can be tested and assembled if desired.

The main differences among MSFC's thermal spray coating and forming processes are layering thickness, operation/equipment cost, and type of base material being coated. Many techniques can remove these coatings, including abrasion and machining as these methods do not produce molecular bonds. MSFC's website at http://map1.msfc.nasa.gov offers additional information on these processes as well as collaboration opportunities.

## *Facilities*

### X-Ray Calibration Facility

MSFC's X-Ray Calibration Facility (XRCF) is a world-class, one-of-a-kind operational site that was constructed in 1975. Over the years, it has gone through many changes to make it a highly flexible facility with a multi-disciplined workforce. As the largest x-ray, optical test site in the world, the XRCF (Figure 2-4) features a 2,000-square foot, class 10,000 area for unpacking and assembling hardware and a 6,000-square foot, class 2,000 vertical laminar flow clean room. The XRCF's vacuum chamber is a 24-foot by 75-foot stainless steel compartment, capable of sustaining temperatures from -180°F to +180°F and vacuums to $10^{-7}$ Torr. The chamber can accommodate in-flight configurations of any payload to be launched from the space shuttle.

The facility's x-ray system produces a nearly parallel beam that travels down a 1,700-foot long, stainless steel guide tube with gate valve isolation from the calibration chamber. The guide tube varies in diameter from three feet at the source of the beam to five feet at the chamber. Internal baffles prevent the scattering of the beam by eliminating rays that hit the sides of the tube. The x-ray source and the chamber are isolated from the surrounding building and the ground to remove any possible interference from seismic disturbances. The high vacuum levels of the chamber can be achieved in six hours, first by mechanical pumps (also isolated from the chamber and the ground) and then by cryogenic and turbomolecular pumps. Additionally, MSFC can isolate the calibration chamber from the guide tube to perform thermal vacuum testing of space shuttle payloads, leak testing of space station modules, space simulation testing, and large space structure bake-outs.

The XRCF is strategically located near the Redstone Arsenal Airport, the Tennessee River, and major interstate highways. As a result, materials and components for testing can be easily delivered to the

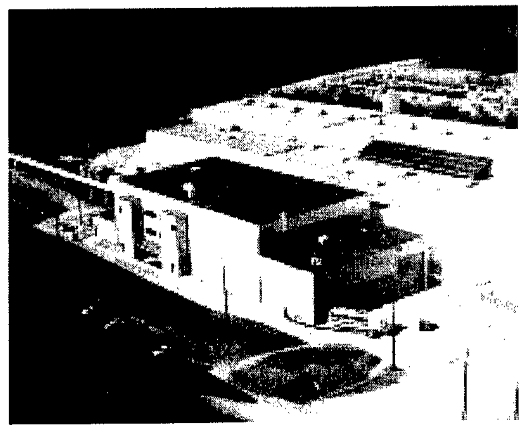


*Figure 2-4. X-Ray Calibration Facility*

facility. All buildings within the XRCF maintain a controlled access and are connected by a secure local area network. Manning levels for normal operations is two to four employees per shift. MSFC's ability to test and calibrate instruments prior to their launch is a significant benefit, thereby reducing unexpected and costly problems/failures before they occur in space.

## *Management*

### ISO-9001 Implementation

In 1995, the NASA Administrator mandated that all NASA centers become registered to ISO-9001. MSFC began working on this objective in May 1996 and completed it by February 1998. Aside from the directive, MSFC viewed ISO-9001 registration as an opportunity to improve self discipline and internal communications; facilitate better communication among all NASA centers; and attain better alignment with support contractors.

The key to successful implementation was fostering effective communications at every level and through every stage of the process. MSFC's quest began with commitment from top management and personal involvement by the Center's Director. ISO was viewed as a management system, not just a quality system. Everyone was involved in the implementation process, which soon became an inherent way of performing MSFC's day-to-day business. The Center established an effective implementation organization and set up teams. An electronic, web-based document control system was also created with an electronic

review and approval process, making instant access/retrieval a reality and improving the currency of policies and procedures. Frequent internal audits were conducted to build accountability and drive the baselining process. MSFC put in place a single corrective action system for the entire Center, where previously ten had been. A capable and trusted outside consultant provided guidance and assistance throughout the implementation and certification processes. General awareness training was conducted as soon as possible in the early stages for 100% of the Center's personnel. This helped minimize any misinformation or misunderstanding. Process specific training was also conducted to address procedure changes and new ISO processes. Continuous communication was applied in multiple media modes (e.g., memos, websites, newsletters, e-mail, posters, organizational representatives).

By far, the single, most effective communication tool at MSFC is its ISO-9000 website (http://iso9000.msfc.nasa.gov:9001/index.html). This site provides a single source for generic and specific information about MSFC's ISO-9000 issues, and is also an excellent reference for other NASA centers or anyone wishing to obtain data on the implementation process. MSFC's ISO-9000 website provides general information on every possible aspect of ISO-9000 plus every detail of MSFC's experience (e.g., historical publications, presentations, clarifications, audit notes, findings). This site is extremely valuable for anyone contemplating or undergoing ISO certification.

The ISO-9001 preparation and certification processes provided MSFC with many lasting benefits. The most important is improved communications. The Procurement Department experienced a 65% reduction in procedures, and other departments have had similar reductions. The Center now has greater rigor in project planning and configuration control planning. Contractor accountability and control has also greatly improved. The ISO process prompted scrutiny and formal mapping of internal processes by organizations, often for the first time. Redundant functions and documents were eliminated, and more discipline was achieved in the control of records, documents, and procedures. Others can benefit from the lessons and experience of MSFC by exploring its ISO-9000 website.

## Marshall's ElecTRonic Office

Over the past few years, MSFC has seen a surge in the number of available electronic tools and Internet/Intranet sites. With so many choices, users often waste valuable time trying to locate the appropriate resource for their work. The need to access pertinent tools, websites, and MSFC-specific documents and regulations led to the development of Marshall's ElecTRonic Office (METRO).

METRO is a website, established within the MSFC Procurement Library, that provides one-stop shopping for up-to-date, web-based information. The site is designed for total coverage and maximum usability for procurement and non-procurement personnel alike. METRO operates as a single point of access for electronic tools, MSFC information, and Internet/Intranet sites. Each site is password protected as appropriate. Internet sites include: NASA Acquisition Internet Service; Federal Acquisition Regulations (FAR) and NASA FAR Supplement; Electronic Posting System; Small Business Innovation Research Program; NASA Procurement Library; Consolidated Contracting Initiative; standardized industrial codes; on-line purchasing sites; and per diem rates. Intranet sites include: ISO-9000 documents; On-line Credit Card Program; Procurement News and Special Events; MSFC Intranet site; Personnel Contact List for Procurement/Finance; and downloading of special documents and forms. Future METRO links are being developed which feature training aids for contract specialists and technical personnel.

METRO has proven to be an invaluable tool for carrying out daily activities at MSFC. Key aspects to introducing METRO to users were its prototype demonstration model to management and its identification of a point of contact for the content/technical aspects of the site. METRO is recognized by MSFC users as the one-stop shop for web-based resources, and is constantly updated to provide the latest and most accurate information. The name, itself, suggests it is a vehicle for going to the right place. METRO saves valuable time for its users, provides user-friendly accessibility, offers unlimited potential for expansion, and operates as the main communication tool for the Procurement Directorate.

## NASA Acquisition Internet Service

In 1993, a presidential memorandum was issued which required all government agencies to streamline their procurement processes via electronic commerce. Previously, vendors seeking to do business with NASA had to search through the Commerce Business Daily (CBD). Reviewing this publication was a laborious process, and many small businesses had limited access to the CBD. To comply with the memorandum and provide small businesses with

greater accessibility, MSFC developed the NASA Acquisition Internet Service (NAIS). This service is an agency-wide, on-line capability that communicates procurement information to industry. Specifically, NAIS provides real-time synopses of business opportunities, solicitations, and a repository of government acquisition websites to vendors seeking opportunities with NASA.

In 1994, NAIS began as NASA's Midrange Pilot Program. The program's objectives were to establish a new set of tools and processes for streamlining the acquisition process, and to exchange information between NASA and potential offerors via the Internet. The original setup used procurements between $25,000 and $500,000, an 80% representation of NASA's purchases. Vendors received electronic messages regarding synopsis information, advance procurement notices, contract award notices, solicitations, and amendments. The Midrange Pilot Program was started at MSFC and, once the concept proved successful, was implemented throughout NASA in 1995. Today, NAIS is mandatory for all competitive acquisitions over $25,000. Procurements of $25,000 or less have the option of using NAIS.

A team approach was employed to design NAIS using representatives from each NASA Center. Team members worked part time on this project in addition to their other duties. The team communicated via weekly teleconferences and monthly video teleconferences, and established an on-line discussion forum, the first of its kind. NAIS was developed by integrating and standardizing the best ideas from all the NASA Centers' websites. Since NAIS was implemented, additional features have been added:

- Search Capability—Allows vendors to search for specific business opportunities.
- E-mail Notification—Allows vendors to receive instant notification of an opportunity once they complete an on-line registration form detailing procurement interests.
- Federal Acquisition Jumpstation — Provides vendors with a single source for government acquisitions. First-ever listing of links to other government agency acquisition websites.
- Financial and Contractual Status System — Provides Internet access to contract summary data. Vendors and congressional staffers can build their own query to obtain information on NASA's current procurement activities. Query criteria include product/service code, dollar value, contract type, contract number, geographic information, and Standardized Industrial Codes.
- Electronic Posting System — Allows contract specialists to post synopses and solicitations directly to the NASA website from their desktops, eliminating the need for a webmaster. In addition, an electronic version of the synopsis is generated and sent to the Government Printing Office for inclusion in the CBD. The success of this system has led to an interagency initiative for a pilot program, which will provide vendors with an electronic web source for all government procurement opportunities.

By implementing NAIS, NASA has made its procurement process more efficient and competitive. This streamlined capability conveys procurement information to vendors on an immediate basis. As a result, NAIS decreased procurement leadtime by 40% and increased the average number of offers per solicitation from 6.1 to 7.2. In addition, NASA and industry realize an overall cost savings of approximately $4.5 million by using NAIS.

## NASA/Air Force Cost Model

Prior to 1990, no standardized cost estimating tool existed at NASA. Instead, numerous spreadsheet models were used. These models relied heavily on volumes of historical data that were searched, analyzed, and inserted into formulas. Additional drawbacks included no formalized training for users, inconsistencies between models, difficulty in showing data traceability, need for engineering judgement, and limited detailed relational analysis capabilities. These models, however, did perform Cost Estimating Relationship (CER) estimates, but provided little more in additional services. As a result, management frequently had to review the findings after cost estimates were generated. In 1990, MSFC's Engineering Cost Office visualized a better process using a single model to meet all needs. Within a few years, MSFC, in conjunction with the Air Force, implemented a viable prototype known as the NASA/Air Force Cost Model (NAFCOM). Since then, NAFCOM has evolved into a cutting-edge cost analysis, modeling, and estimating tool.

NAFCOM consolidates numerous existing cost models and databases used throughout NASA, and brings cost estimating into compliance with today's state-of-the-art software environments. This fully automated software tool employs an easy-to-use spreadsheet environment to predict the cost of space hardware at the subsystem and component levels. The information within NAFCOM represents the best of

the aerospace project data from the Resource Data Storage and Retrieval (REDSTAR) library, NASA's major repository of cost, technical, and programmatic information dating back to the 1960s. The REDSTAR library contains over 22,000 documents and one million pages of information, and maintains a website-based user interface to coordinate these components into a single user-friendly interface.

Creating cost estimates within NAFCOM are based on specific analogy and database averaging techniques. Specific analogy CERs are created by selecting analogous data points from the database within NAFCOM. The database's average CER represents the average of the data population. To create a specific analogy CER, the user first selects the appropriate database (e.g., manned spacecraft, unmanned orbiting or planetary spacecraft, launch vehicles, liquid rocket engines) and then the appropriate data level (e.g., group, subsystem, component, unit). Within each data level, the user selects:

- Group level items (e.g., structures, thermal, and mechanisms; electrical power and distribution; command, control, and data handling);
- Subsystem level items such as typical aerospace hardware (e.g., thermal communications, attitude control); and
- Component level data (e.g., batteries, support structure, rate gyros, cabling).

After making these selections, the user further refines the CER database by choosing from more than 100 filters within the cost model that relate to the technical and programmatic characteristics of the data points. The available filters are determined by the system and subsystem choices at the data level entry. Once the data levels and filters are applied, the user selects specific programs from a list of missions, enters weights, and applies complexity factors so NAFCOM can determine the estimated cost. All users are trained on this tool.

Currently released as version NAFCOM99, this tool is consistent, efficient, and effective at defending cost estimates. NAFCOM operates as a single cost estimating system that meets users' needs, and provides management with a standardized format for reviewing estimates. As a result, this tool reduced the frequency of reviews and greatly improved the creditability of the system.

## New Technology Transfer Program

Technology transfer has always been a major thrust for the NASA Centers. In the past, MSFC focused its technology transfer resources on assisting industry and small businesses, whereby NASA field agents located industry problems and provided companies with up to 40 hours of free technical assistance. However, such services eventually put a strain on MSFC's resources and detracted from the Center's primary mission focus areas. Inadequate resources were applied to technology development and deployment partnerships, intellectual property management, patent licensing, technology transfer education and outreach, and success story case studies. To better meet the needs of internal and external customers, MSFC restructured its technology transfer program in 1997.

The structure of the New Technology Transfer program was changed from a hierarchical, stovepipe framework with little communication/interaction among units to a flat organization with an integrated, cross-trained team. In addition, the Center shifted its primary focus away from gratuitous extension services and set up eight interdependent mission areas: Technology Development; Small Business Programs; New Technology Reporting; Facilities Commercializations; Technology and Software Commercialization; Technology Deployment Partnerships; National, Regional, and Local Strategic Alliances; and Technology Education and Outreach Projects for Economic Development. These areas provide MSFC with a more cost-effective, balanced portfolio of quality products and services. New objectives were identified to help U.S. industry become more globally competitive, specifically through national goals for the civilian space program and responsibilities associated with transferring NASA technology. Under this new approach, MSFC applied business principles to government technology transfer processes to gain efficiencies, improve performance, and align with mission requirements. The infusion of this strategy into NASA's traditional technology transfer mechanisms revitalized the overall program. As a result, numerous methods and agreements now exist for transferring NASA technology to the private sector:

- Research and Development Agreements — Arrangement between NASA and private companies, whereby the expenses associated with NASA facilities, personnel, equipment, technology,

and/or capabilities are fully reimbursable, partially reimbursable, or non-reimbursable by the private companies.

- Joint Research Agreements—Arrangement that is jointly funded and undertaken by NASA and one or more private sector companies.
- Small Business Innovation Research Program and Small Business Technology Transfer Contracts—Programs designed to benefit small and disadvantaged businesses.
- Cooperative Agreements, Grants, and Contracts—Methods used to stimulate technology development and commercialization. Many NASA technologies are available for licensing with flexible agreements and mutually beneficial exclusive and non-exclusive arrangements.

NASA uses various publications to highlight its technology transfer opportunities and success stories. *NASA Tech Briefs* is a monthly magazine that features technical articles on emerging technologies from the NASA Centers. This magazine is published electronically (http://www.nasatech.com) and in hard copy. *Aerospace Technology* is a bi-monthly news summary on how NASA technology is being applied, and covers the intricacies of actual technology transfer. This news summary is accessible at http://www.nctn.hq.nasa.gov. *NASA Spinoffs* is an annual compilation of success stories of NASA technology being applied to improve medical, environmental, manufacturing, construction, transportation, safety, consumer, and computer products. This publication is available electronically (http://www.sti.nasa.gov/tto) and in hard copy. Users who visit the website will find a searchable database for browsing technology transfer case studies. Additional information can be obtained directly from the MSFC Technology Transfer Office by visiting its website (http://www.nasasolutions.com) or by contacting the office at (256) 544-6700.

Since implementing its new approach to technology transfer, MSFC has compiled success stories in all eight mission areas and achieved greater customer satisfaction, both internally and externally. Technology transfer now operates across all mission areas interactively and synergistically. During the past year, the number of patent licenses increased by 108% and the number of partnerships increased by 67%. The entire effort is contributing directly to U.S. national objectives for developing and commercializing space technology.

## Reusable Launch Vehicle Case Study Model Initiative

MSFC's Engineering Cost Office developed a discounted cash flow model to analyze commercial business cases for the Reusable Launch Vehicle (RLV). As a result of this effort, NASA redefined government-industry relationships and envisioned a new way of investing in large scale technology development projects. Traditionally, government and industry justify these types of projects on the basis of a cost-benefit analysis. However, the economics of a cost-benefit analysis are different for government and industry. Large scale technology development projects are usually long-term, high-cost investments which are acceptable to government, but not industry. The difference is the cost of capital which is a significant factor for industry. Government can afford to wait 40 or 50 years to realize a payback, but industry's horizons for return-on-investment are much shorter.

Typically, government relies on industry to shoulder much of the development cost and risk for major systems. However, some technologies are too important to wait for a market-driven development effort. Historical examples include railroads, aviation, and electrical power. In these cases, the government provided assistance in funding, incentives, and other mechanisms to spur development. Revolutionary technologies create new industries and open up vast new frontiers of economic development. RLV is such a technology and will enable NASA to reduce launch costs by an order of magnitude, thereby increasing launch activity and further driving down launch costs. Lower commercial RLV prices should lead to increased U.S. market shares in the global launch business and development of commercial space industries. This situation, in turn, will provide increased exports, employment, and tax revenues.

MSFC's model employs discounted cash flow analysis to determine the level and type of incentives and/or investments that NASA can make to encourage commercial development and reduce risks to an acceptable level for industry. This model is an outgrowth of the X-33 and follow-on programs in which independent industry teams each developed their own tools for modeling the business cases for the RLV. These cases were then integrated by MSFC into the RLV Case Study Model to provide NASA with an analytical capability to independently examine the business plans being proposed by industry. The RLV Case Study Model was designed to quantify the business risks involved in a commercial RLV, define key

business parameters, and gauge the sensitivity of business variability to these parameters. The model provides flexibility to analyze the effects of various launch parameters and incentive schemes, and addresses both government and industry perspectives. In addition, MSFC's model is expandable for defining and calculating metrics (e.g., internal rates of return, net present values, life cycle cost), and takes into account microeconomic metrics (e.g., industry profitability, government savings) and macroeconomic considerations (e.g., jobs, corporate and personal taxes). Figure 2-5 depicts the current RLV model structure. New enhancements being added include market elasticity considerations and NASA's life cycle costs of a space transportation architecture.

The shift to commercial launchers enables NASA to focus on the new frontier of space transportation technology development and the organization's ultimate customers: the infant space transportation industry and the yet-to-be-developed human space transportation industry. MSFC's model shows NASA the value of providing appropriate incentives, investments, grants, direct capitalization, and in-kind contributions to industry. This initiative has proven that long term investment in technology and transportation infrastructure is an appropriate role for government. In return, the investment will reduce launch costs for the government and spur the development of the commercial space market with significant macroeconomic benefits to the country. MSFC's approach can be easily adapted for use by other government agencies as well.

## Space Leadership Council

Improving customer satisfaction has always been embedded in MSFC's enterprise goals and objectives. In the 1990s, the Center entered into a new era of doing business through better leveraging and partnerships where each partner is considered to be a customer. One of the first tests of using a leveraging/partnership approach was ISS involving MSFC; NASA Johnson Space Center (JSC); Teledyne Brown Engineering; Boeing; and Defense Contract Management Command, Birmingham. Recognizing that traditional practices were no longer conducive to this arrangement, MSFC and its partners established the Space Leadership Council (SLC) in January 1996. The SLC is a way to provide contractually compliant NASA products and services by improving communications and key processes to the satisfaction of its customers.

To ensure the project's success, the SLC wanted to make improvements in communications, processes, proactive teamwork, performance and recognition, and employee development. Therefore, the group examined the common enterprise missions, goals, and

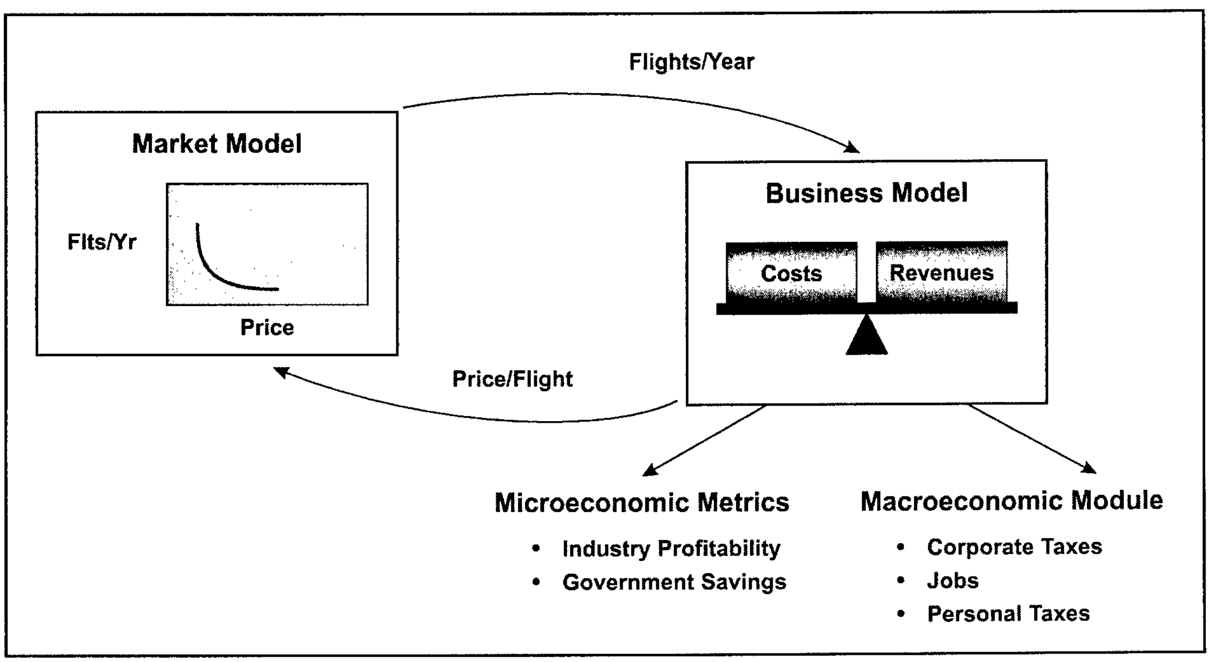



*Figure 2-5. Current RLV Model Structure*

objectives of its respective organizations to formulate a council that operated within these parameters. The SLC next set goals to establish, facilitate, and maintain a common communications network; meet or exceed NASA requirements and expectations for delivery of products and services; establish a viable commitment to achieve an honest focus on common goals; and improve the performance of all participants who supported the NASA project. To achieve these goals, the SLC formulated strategies that would identify customer needs and concerns, determine root causes and develop solutions, localize recurring problems, eliminate errors, plan for continuous improvement, and communicate successes and lessons learned. The SLC process consists of monthly meetings that rotate from partner to partner, where critical issues are addressed and mutually agreed priorities are set. Plans are jointly developed in pursuit of the group's vision. Process action teams were also formed to produce fundamental change and process improvements. The SLC recognizes the performance and accomplishments of significant contributors at all levels throughout the partnership.

Since the SLC was implemented, the process action teams have actively pursued and impacted various issues such as personnel training needs, improvements in the acceptance data package process, the handling/shipping of high-dollar hardware, and a process for handling Alert Bulletins. The SLC is accomplishing its goals, and continues to evolve. As a result, communications have greatly improved and a common understanding is shared among all the partners. Other accomplishments include the establishment of a structured cooperation, collocation of partners to facilitate teamwork, and the sharing of quality assurance databases.

## Web-Based Data System Solutions

MSFC's Engineering Systems Department developed a series of Web-Based Data System Solutions for information and document management applications. Prior to these systems, various uncontrolled, undocumented processes as well as hardware and software platforms were used at the Center. This situation created problems in processing and accessing information; handling security; and changing or developing systems. As MSFC began downsizing, these problems became more acute. Web-based data systems were recognized as a way to establish a paperless environment in support of ISO-9001 certification, and provide immediate accessibility to information per NASA's faster, better, cheaper approach.

MSFC's systems are based on a web development tool called Tango designed by Pervasive Software, Inc. in Austin, Texas. Tango is a cross-platform, visual productivity tool for the distributed electronic enterprise. This tool allows developers and organizations to efficiently and cost effectively tie distributed data and computing resources into practical, web-based Intranet information systems. Tango is one of several COTS tools that provides a programming environment to facilitate the creation of distributed knowledge management or systems management applications. Traditional mainframe and client server architectures are too inflexible for implementing close, but fluid, inter-business integration which is driving the increased adoption of more flexible, loosely coupled web-distributed systems. The goal of multi-tier web-distributed applications like Tango is to deliver all of a corporation's information assets and resources to the point of use or need with real-time responsiveness. For the web-based system applications developed at MSFC, Tango was used as a translator (Figure 2-6) between a user's web browser and any source database. Unlike static networks in which the user re-

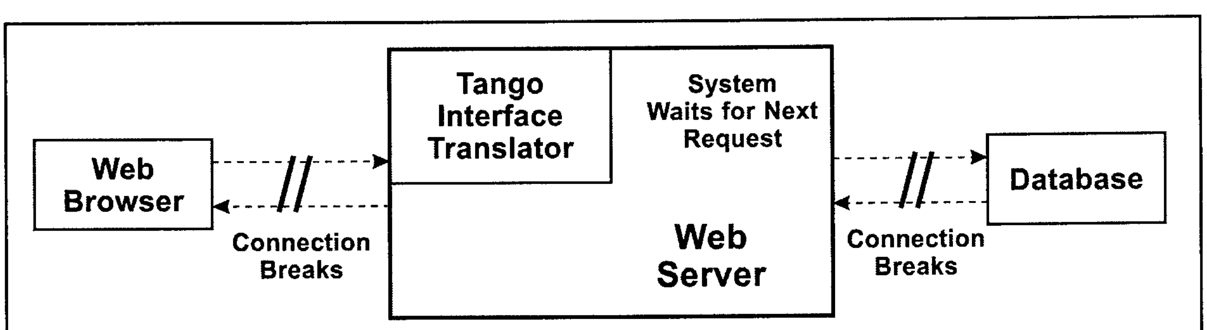



*Figure 2-6. Web-Based System Configuration*

mains connected to the server, a web-based system only requires the user to be connected to the web server when completing an action, then the connection is broken. This approach allows the user to draw information from any accessible database over the Internet.

To date, more than seven major web-based system applications have been developed at MSFC. One example is the Program/Project Data System (PDS). This tool provides project managers with a documented, ISO-compliant system to review and approve in-house and external documentation. Features include identification and tracking of data requirements, on-line status reports, and automatic feeding of information into Document Control Board input screens to prevent re-entry of information. PDS also provides the capability to reserve and track the status of MSFC document numbers and program/project-specific document numbers. This system uses a secure electronic documentation review process and is being upgraded to include a configuration control documentation review process.

All of MSFC's web-based systems are ISO compliant. They provide documented control; electronic review and approval capability; security; and accessibility which is not platform dependent. The only requirement for access is a web browser, and the systems are fully compatible with existing user processes and software. These systems also enable MSFC to realize significant savings as a result of reduced time required for system development and changes, and reduced resources required for operation and maintenance.

# Section 3
# *Information*

## *Design*

### Advanced Concept Research Facility

MSFC's Advanced Concept Research Facility is in the process of developing many alternative propulsion systems for use in a space environment. Most of these methods are still in the development stage and will, if accomplished, redefine the limit of travel which is possible today. Some of the cutting edge technologies being studied include: Solar; Nuclear; Fusion; Pulsed Propulsion and Power; and Magnetohydrodynamic Propulsion. Many breakthroughs and discoveries have been uncovered during this research. Another method of potential propulsion being studied at this facility is the modification of Gravity Utilizing Superconductors.

The Pulsed Propulsion and Power research is still in the development stages and should have applications in power generation as well as propulsion. The Magnetohydrodynamic Propulsion research is facing funding constraints due to this technology's physical limitations (e.g., weight), current configuration, and non-applicability to the space program. The modifications of Gravity Utilizing Superconductors should lead to many potential uses including bearing material as applicable to cryogenic bearing development.

### Gas Dynamic Mirror Fusion Propulsion Engine

One of the most critical aspects for performing a manned mission to Mars will be the space vehicle's propulsion system. To minimize the crew's physical degradation and exposure to hazardous galactic radiation, this propulsion system must be able to complete the trip in a relatively short time. Other requirements include moderate size and the ability to produce large values of specific impulses and thrust. The best propulsion system currently available is nuclear fusion. This method produces impulses of 130,000 seconds, compared to nuclear fission at 950 seconds and chemical propulsion at 450 seconds. A space vehicle using a nuclear fusion system could complete a round trip to Mars in months rather than years.

MSFC's Gas Dynamic Mirror (GDM) system is an example of a magnetic mirror-based fusion propulsion system (Figure 3-1). The Center maintains this system in steady state by injecting particles in the region of the homogeneous magnetic field to effectively balance the plasma loss through the mirrors. GDM's design is relatively simple, primarily consisting of a long slender solenoid that surrounds a vacuum chamber containing plasma. The bulk of the fusion plasma is confined by magnetic fields which are generated by a series of toroidal-shape magnets in the central section of the device. Stronger end magnets called mirror magnets prevent the plasma from escaping too quickly out the ends.

On October 23, 1998, MSFC tested the plasma injector system of its GDM Fusion Propulsion experiment, and successfully produced a plasma. The purpose of the plasma injector is to introduce a gas into the GDM system and heat it until it becomes plasma. The injector operates by using a microwave antenna operating at 2.45 GHz to induce electron cyclotron resonance heating of the gas. As the hot electrons stream out of the injector in response to the imposed magnetic fields, they create an electric field which drags the ions along this path. This phenomenon is called ambipolar diffusion and is used here to raise the ion temperature. The effect requires that the magnetic fields produced by the solenoid magnets be present. For this test, however, these magnets were not installed so the ions remained in a cold state.

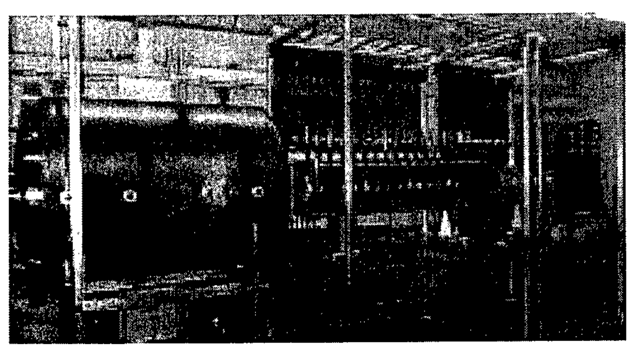


***Figure 3-1. Experimental Gas Dynamic Mirror***

## High Strength Aluminum Casting Alloy for High Temperature Applications

A hypereutectic alloy such as A390 is a conventional aluminum alloy used to make pistons in U.S. automotive engines. This alloy has adequate strength, is easily cast, and is low in cost. However, new congressional regulations require U.S. automobile manufacturers to continue to lower hydrocarbon emissions.

In a Conventional Piston Design, the large crevice volume between the piston and the cylinder at the top of the piston is a significant contributor to hydrocarbon emissions. A small volume of unburned gasoline/air mixture is trapped in this crevice volume during each firing stroke, and a portion of this unburned mixture is then expelled on the subsequent exhaust stroke of the piston. These unburned gases contribute directly to hydrocarbon emissions of the automobile. The Ford Motor Company in Dearborn, Michigan has developed and tested a Modified Piston Design. As expected, the thinner piston topland with its greatly reduced crevice volume significantly lowered hydrocarbon emissions. However, a typical alloy such as A390 aluminum alloy used in the design has inadequate tensile strength in the required 500° to 600° F temperature range. Figure 3-2 shows a comparison between the Conventional and Modified Piston Designs.

In 1995, MSFC's metallurgists began working with Ford under a Space Act Agreement to develop a new, castable aluminum alloy that had a 30% improvement in tensile strength during operation in the required temperature range. The result was an aluminum-silicon alloy that meets or exceeds all original automotive criteria. Figure 3-3 shows a 600° F, tensile strength comparison of available aluminum alloys against the NASA alloy. The projected cost of the aluminum-silicon alloy is 95¢ per pound versus 87¢ per pound for A390. Since less of the new alloy material is required due to its higher strength, the cost per piston is expected to be comparable. MSFC has currently filed a patent on the aluminum-silicon alloy, and negotiations are ongoing with Ford and other U.S. automobile manufacturers regarding its use.

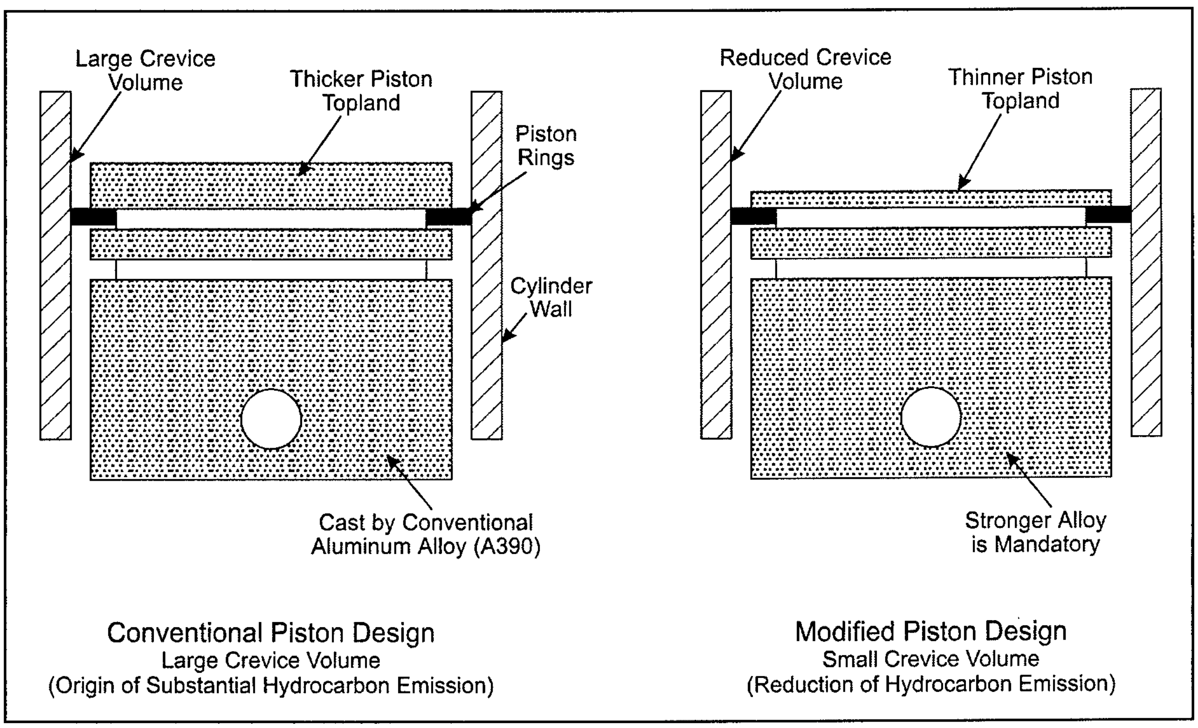



***Figure 3-2. Conventional versus Modified Piston Design***

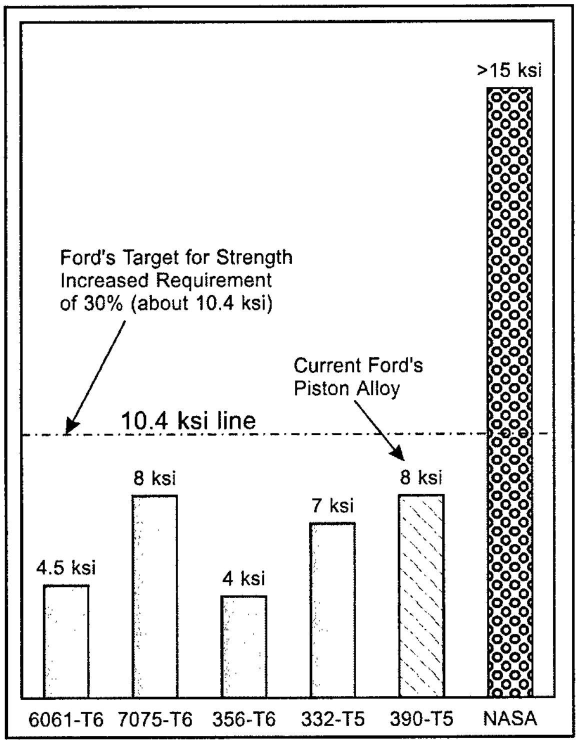



***Figure 3-3. Aluminum Alloys Tensile Strength Comparison at 600° F***

## Marshall Electromagnetic Compatibility Design and Interference Control Handbook

Previously at MSFC, electromagnetic interference (EMI) issues were sometimes not addressed during the design phase. Only after a unit experienced failures during testing were the EMI engineering staff called into the situation. This approach led to expensive redesign costs and/or waivers being issued before the unit could be fielded. In 1995, MSFC developed the Marshall Electromagnetic Compatibility Design and Interference Control (MEDIC) handbook to help electrical engineers use practical information in designing for the mitigation of EMI.

The MEDIC handbook was tailored to the needs of the NASA community and provided:

- Guidelines to translate EMI requirements into electrical design requirements.
- Design techniques to minimize the potential for EMI.
- Practical measurements and prediction techniques to identify potential EMI problems during the early design phase.
- Practical retrofit fixes for EMI problems discovered after the design phase was completed.

The handbook was developed independently from qualification or acceptance testing. In addition, the EMI engineering staff used a separate laboratory to prove-out techniques, and used common electrical test equipment to measure results. This approach enabled electrical engineers to prove-out the design before performing expensive EMI testing.

Since 1995, the EMI engineering staff has distributed at least 1,000 copies of the MEDIC handbook. Electrical engineers from organizations external to MSFC now commonly contact the staff to discuss EMI design issues as well as test problems. The MEDIC handbook has been a useful tool in the EMI design area, and demonstrates practical approaches to addressing EMI in the spaceflight industry.

## Quantitative Risk Assessment System

Probabilistic risk assessment is a method used to calculate an overall system risk by combining high level event probability distributions with probability distributions from each lower level item or process. Although complicated and laborious, this powerful tool provides accurate results for quantifying the degree of risk. In 1996, NASA recognized the need for such a tool to assess overall system and upgrade risks of the space shuttle. Under contract to MSFC, the University of Maryland developed the software for the Quantitative Risk Assessment System (QRAS).

MSFC uses QRAS to assess the reliability of the space shuttle and its major components; help perform trade-off evaluations; rank space shuttle failure modes; perform sensitivity analysis; assist in other analysis efforts; and evaluate proposed space shuttle upgrades (e.g., propulsion element). QRAS is particularly useful for large, complex systems because it arranges data in a hierarchical, tree-like structure. The hierarchy format documents the relationship between elements, components, and failure modes or basic event. Next, a functional event sequence diagram (FESD) is developed for each basic event, showing where each process is inspected, tested, or evaluated. Probability parameters are inserted into each process in the FESD, along with the appropriate justification for using the probability selected. A powerful capability of QRAS is that probabilities can be entered as time based, and various distribution functions can be included. This approach allows users to evaluate risk over a specific time period as well as obtain confidence levels on the resulting system risk.

Concurrent with the above procedures, an event probability distribution is inserted into the model. The event probability distribution defines failure probability during operation and is based on flight test data, probabilistic structural models, and general engineering judgement. QRAS then calculates the resulting system level risk based on the input data using Monte Carlo simulation techniques. Since the risk is expressed as a probability density function, a confidence level can be associated with the end result. QRAS also operates as a database which allows users to input the justification and source of each risk probability used in the model. The hierarchical format lets users manipulate the information to examine the lower levels of the system architecture.

QRAS calculates an overall system risk by combining the probability of occurrence of all system failure modes. This tool's windows-based, user friendly design makes it advantageous over traditional probabilistic risk assessment methods. MSFC uses the end results to project system life, estimate inspection intervals, and determine flight readiness support. Repetitive iterations of the risk assessment can also be used to perform trade studies by comparing either two design concepts or a new proposed design against a baseline. Although specifically designed for NASA's Space Shuttle program, QRAS can be used on almost any program where probabilistic risk assessment is needed. The tool is currently undergoing a sequence of peer reviews, and a final baseline is expected by October 1999.

## Solar Thermal Propulsion

In the distant future, low cost propulsion will be needed for interplanetary travel and unmanned exploration. NASA foresees Solar Thermal Propulsion as a way to boost future payloads from a low earth orbit to a geosynchronous earth or higher orbit. These payloads would also undergo round trips of 30 days to transit between orbits. Solar Thermal Propulsion is an excellent choice because it requires only one propellant gas and combines moderate thrust with moderate propellant efficiency. For more distant travel, a solar thermal engine using this propulsion would act like a simple, efficient tugboat in space.

In the operation of a solar thermal engine, the absorber functions as a heat exchanger. Sunlight is concentrated via a lens or mirror, and then focused into the absorber cavity. This cavity is comprised of three, vacuum plasma, spray-formed coaxial shells with two, double helical flow passages through which the propellant gas flows. As the gas flows through the helical channels, it absorbs energy, expands, and then exits the nozzle. Through this process, solar energy is converted to kinetic energy-thrust. The test units built at MSFC are designed to produce two to two-and-one-half Newtons of thrust using hydrogen as the propellant. The intended service temperature of the ground test absorber cavity is 2450° C, with an internal gas pressure of 170 kPa, using hydrogen as the working fluid.

MSFC's Solar Thermal Facility has built the heliostat mirror, concentrator, quartz-windowed vacuum test chamber, absorber/thruster, and gaseous hydrogen plumbing. The mirror measures 20 feet by 24 feet, and is positioned 200 feet from the concentrator. During a test, the mirror follows the sun via tracking software and redirects the solar energy to an 18-foot diameter concentrator. Using 144 hexagonal reflective sections, the mirror focuses incident solar radiation through the test chamber's front-fused silica window and into the opening of the absorber/thruster.

# *Test*

## Army/NASA Virtual Innovations Laboratory

MSFC's Engineering Systems Department, in conjunction with the U.S. Army's Redstone Arsenal, has developed the Army/NASA Virtual Innovations Laboratory (ANVIL). This laboratory develops effective human-interface-to-hardware designs by combining human modeling and analysis tools with virtual reality technologies. The process involves importing computer aided design (CAD) models into an analysis package, where the creation of human models evaluate the reach, work, and visibility envelopes. Analysis entails partially-immersive or fully-immersive experiences for the user. The former permits the human engineer designer to evaluate the design from the observer's perspective by means of a computer screen. The latter allows the designer to see and touch the elements of the human model.

ANVIL uses a variety of virtual reality and human engineering software including CAD packages for model translation and modification; virtual reality tools; and human factors analysis applications. Supporting hardware consists of high-end workstations and virtual reality input/output devices such as gloves, navigation aids, head-mounted display monitors, body position sensors, and auditory simulators. MSFC has

used ANVIL's capabilities for spacelab hardware design, ISS hardware development of extra-vehicle activity, ground support of propulsion systems, and workstation layout. ANVIL also supports immersive collaboration over networks which allows users in remote locations to interactively train with one another, while being monitored by training personnel.

ANVIL provides a virtual reality environment so users can evaluate interface designs and determine the most effective setup prior to actual contact. Since establishing this virtual innovations laboratory, MSFC has realized significant savings in design time and fabrication costs.

## Cryogenic Bearing Testing

Cryogenic bearing testing requires special requirements such as bearing test rigs to duplicate cryogenic turbopump conditions, and computer modeling codes to design special bearings. In the early 1980s, MSFC formed a multi-discipline team consisting of experts in tribology, design, test, materials, and fabrication to initiate a Bearing Test program. The team addressed the cryogenic requirements, fabricated a test rig, and began testing. Contracts were also awarded to companies to design low friction lubricating cages, develop better bearing materials, and refine the bearing modeling codes.

MSFC's Bearing Test program fostered many advancements such as improved bearing materials. New low friction lubricating cages consisting of LOX compatible oils, carbon composite cages, and Salox cage inserts were also developed. Test results led to a better understanding of heat generation, hertzian stresses, wear life factors, dynamics of elements, and internal geometry changes. This information was incorporated into the computer bearing design codes of SHABERTH/SINDA, ADORE, and AB JONES.

Future turbopumps will spin faster and require more power, and the new hydrostatic bearings are well suited for this application. MSFC also designed and built a test rig that can run hydrostatic bearings and, with modifications, can run rolling element bearings in liquid nitrogen, liquid oxygen, and liquid hydrogen (LH2). The LH2 testing capability is unique to MSFC. Although it was not directly related to manufacturing, the Bearing Test program led to new bearing technologies and improved computer-modeling codes for these types of bearings. Applications for this technology include aerospace bearings, high-speed spindle bearings, industrial air conditioning, and high-speed turbo vacuum pumps.

## Integrated Space Station Electromagnetic Compatibility Analysis System

Six different international partners are designing and building major elements of ISS. As a result of this arrangement, electromagnetic compatibility (EMC) and electromagnetic interference (EMI) become vital keys to successfully completing the space station. To address these issues, MSFC developed the Integrated Space Station Electromagnetic Compatibility Analysis System (ISEAS). This integrated database system keeps track of EMC between devices and systems on ISS, and enables engineers to evaluate the effects of EMI on flight systems. Potential EMC problems can then be identified and resolved in a timely manner.

ISEAS operates by matching the EMI test results on individual hardware items with their wiring configuration and physical location within ISS. This information permits EMC engineers to assess various parameters (e.g., transient effects; conducted emissions versus conducted susceptibilities; radiated emissions versus radiated susceptibilities) and focus on areas of potential concern.

Early verification of EMC is essential to the ISS project. MSFC is currently using ISEAS to analyze EMC for ISS Flight 2A, the second module of ISS to go into orbit. The 'A' designates that this component is supplied by the United States. The full benefit of ISEAS will be realized in about five years when the number of avionics systems and components on the ISS significantly increases. Once fully implemented, ISEAS will facilitate the timely identification and resolution of potential EMC problems.

## Long Term Vacuum Testing of Lubricants

Lubricants used for space applications must be able to operate in a vacuum environment. Parameters include low vapor pressure, wide temperature range, and minimal outgassing. To determine which ones are compatible for NASA missions, MSFC performs long term vacuum testing of lubricants. In most cases, these lubricants are evaluated in a vacuum environment over a one-year period.

Lubricants in a vacuum environment tend to outgas at a much higher rate. This phenomena causes them to loose their beneficial properties and, in some cases, condense on nearby objects. Finding lubricants which possess superior space operational properties

can best be accomplished in a vacuum test apparatus (bell jar). Each bell jar contains four samples of five different lubricants, which are tested in 20 small motors. During the test period, the motors are periodically examined for failure. At the end of one year, the bearings of each motor are removed and examined. MSFC then identifies the cause of failure (motor armature or lubricant); measures the lubricant's mass loss to determine the outgassing effect; performs a visual inspection with an optical microscope; and calculates the bearing wear (depth of wear track on bearing races) via a Taly-Surf Profilometer. Due to the ban on ozone depleting cleaners, MSFC is currently investigating other ways of cleaning the bearings. Similar testing is performed on oils, but the setup typically uses one motor (sometimes two) per workstation.

MSFC's long term vacuum testing of lubricants is a unique capability. The Center incorporates all test data into a central lubricant database, which engineers extensively use to select lubricants for space applications.

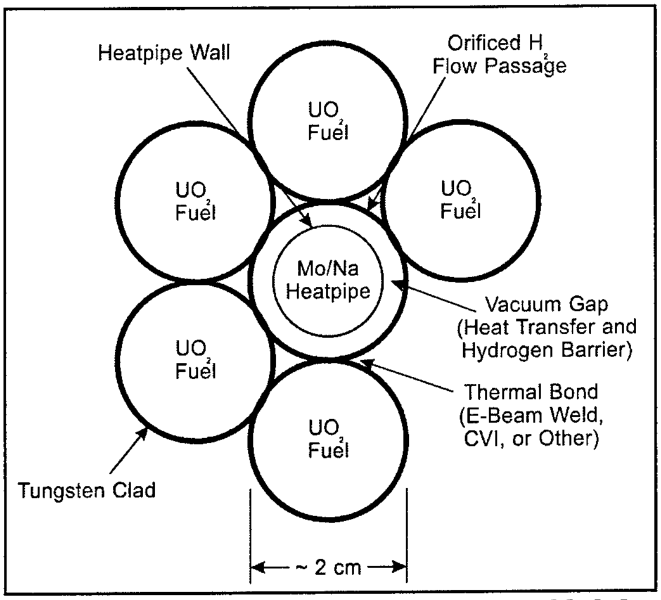


***Figure 3-4. Heatpipe Bimodal System 5-pin Module***

## Nuclear Fuel Element Simulation

MSFC is currently testing various forms of alternative propulsion methods. One such method is the Heatpipe Bimodal System (HBS), designed for nuclear thermal propulsion. The Center's objective is to fabricate and electrically test an HBS module in order to determine its design limits and operational characteristics. Several modules will then be grouped together in a quarter core arrangement to investigate the interactions between the modules under various operational and fault modes.

The HBS uses specially designed fuel pins which essentially allow for complete system testing using electrical heaters. This approach eliminates the need for large, expensive nuclear qualified test facilities. In addition, the HBS is designed with proven fuel technologies in a modular system which reduce costs and development risks. The HBS is a near-term, low-cost, nuclear electric power and thermal propulsion system that can provide moderate levels of thrust and power for many space applications. Heat generated in the fuel is transferred by conduction to the primary module heatpipes. Propulsion is obtained by flowing hydrogen through the interstitials of the core. The system (Figure 3-4) is a 100 kWt-uranium oxide fueled concept that can deliver 250 Newtons of thrust at a specific impulse of 800 seconds. A vacuum gap surrounds the heatpipe to prevent hydrogen ingress and undesirable heat transfer.

Currently at MSFC, an electrically heated fuel element in a power-only configuration HBS has been tested to 1400° K in a vacuum. The Center is also in the process of constructing an HBS module along with a test chamber, that will be capable of electrically testing a full core HBS. Over the next two years, MSFC plans to electrically test a quarter core and possibly a full core HBS configuration to understand the details of heat transfer and fluid flow interactions within the core. The Center also expects to conduct zero power critical testing of an HBS module to determine the neutron flux distributions and criticality limits.

## Optical Plume Anomaly Detection

The Optical Plume Anomaly Detection (OPAD) is a system that analyzes and characterizes emitted spectrum from rocket plumes by monitoring the ultraviolet, visible, and near-infrared regions of the spectrum. Through the detection of metals in the exhaust plume, information relative to the degradation of hardware can be gathered and used for readiness and maintenance decisions. Although spectrum analysis was commonplace in the jet engine industry, the size and weight of the monitoring devices excluded this technology from the space industry. Today, the instrumentation is much smaller and lighter.

In 1986, MSFC's engineering staff began investigating the use of spectrum analysis as a possible method of determining the readiness status of rocket engines. This method is expected to foster rapid decisions, independent of other physical inspections, regarding an engine's readiness. The Center is developing OPAD in three phases:

- Phase A — Concept proven with test stand off-mounted optics and spectrometer using baseline software.
- Phase B — Feasibility proven with test nozzle mounted optics and vehicle mounted COTS spectrometer, and complete/integrate data software modules and analysis package.
- Phase C — Space shuttle flight experiment scheduled for mid-2000 and use on subsequent space shuttle flights.

In Phase A, MSFC collaborated with universities, Air Force/AEDC, and other NASA organizations to define goals, identify problems to be solved, decide what skills were needed, and determine the overall methodology and processes needed to address hardware and data analysis tools. In Phase B, the use of COTS hardware proved the feasibility of being able to mount the system on flight hardware due to small and light instrumentation. Phase C is now being planned with flights on space shuttle missions starting in mid-2000.

OPAD has proved to be a successful method of monitoring the status of a rocket engine by studying the existence of anomalous material in the engine plume. This method has been approved for space shuttle missions, and will enable MSFC engineers to make more informed decisions regarding maintenance and engine readiness.

## Orbital Atomic Oxygen Simulation Facilities

MSFC has developed and implemented orbital atomic oxygen simulation facilities based on the physical characteristics of a low earth orbit environment. This capability is used to determine the long term exposure characteristics of objects launched into space. Previously, no means existed for examining the interaction of materials with orbital atomic oxygen. In November 1982, the Center first began studying this area via the Evaluation of Oxygen Interaction with Materials (EOIM)-1 on STS-5. Subsequent studies include EOIM-2 (August 1983); EOIM-3 (August 1992); the STS-41G Atomic Oxygen Interaction Experiment (October 1994); and the Long Duration Exposure Facility (April 1984 to January 1990).

Orbital atomic oxygen simulation involves the generation of atomic oxygen. MSFC employs three methods for achieving this task: (1) thermal plasma ashers; (2) out-of-field atomic oxygen drift tube simulators; and (3) 5 eV neutral via the Atomic Oxygen Beam Facility. Each method generates atomic oxygen plasma on the surface of the material under test. The radiation within the plasma represents the spectral line of atomic oxygen. By measuring the magnitude of the spectral line intensity, MSFC can calculate a relative figure-of-merit that is proportional to the strength of interaction between the atomic oxygen and the test material. Each method has different strengths and weaknesses based on cost, safety, the atomic oxygen purity in the plasma, and the sample's heating characteristics. MSFC's current atomic testing activities involve materials qualification for anodized and alodine aluminum and nickel; kynar shrink tubing; aplix; super beta; labels; O-rings; slidewire; targets; teflon overcoats; pro seds; and the NASA Jet Propulsion Laboratory's flight experiments. Future activities include continued support for ISS and solar sails.

MSFC's orbital atomic oxygen simulation facilities provide a robust means for simulating orbital atomic oxygen in a low earth environment. The Center performs this service for NASA missions as well as vendors and contractors. This unique capability enables the space industry to determine the long term exposure characteristics of objects launched into space.

## Space Environmental Effects Testing Capabilities

MSFC has established the Combined Environmental Effects Test-Cell 3 (CEETC3), a space environmental effects testing facility used to simulate combined space environments. The CEETC3 enables the Center to test, evaluate, and qualify materials for use on external surfaces in space. Typically, materials are exposed to laboratory simulations of space environments followed by flight experiments, when possible.

The CEETC3 exposes temperature-controlled samples to simultaneous multi-environmental sources such as protons, high energy electrons, low energy electrons, vacuum ultraviolet (VUV) radiation and near ultraviolet (NUV) radiation. The facility (Figure 3-5) generates protons of 30 to 700 keV energy and electrons from 0.22 to 2.5 MeV energy by using two particle linear accelerators. Electrons ranging from 1 to 50 keV energy are generated from an electron gun. Two ultraviolet radiation sources are used: a mercury-xenon lamp for NUV and a deuterium lamp for VUV.

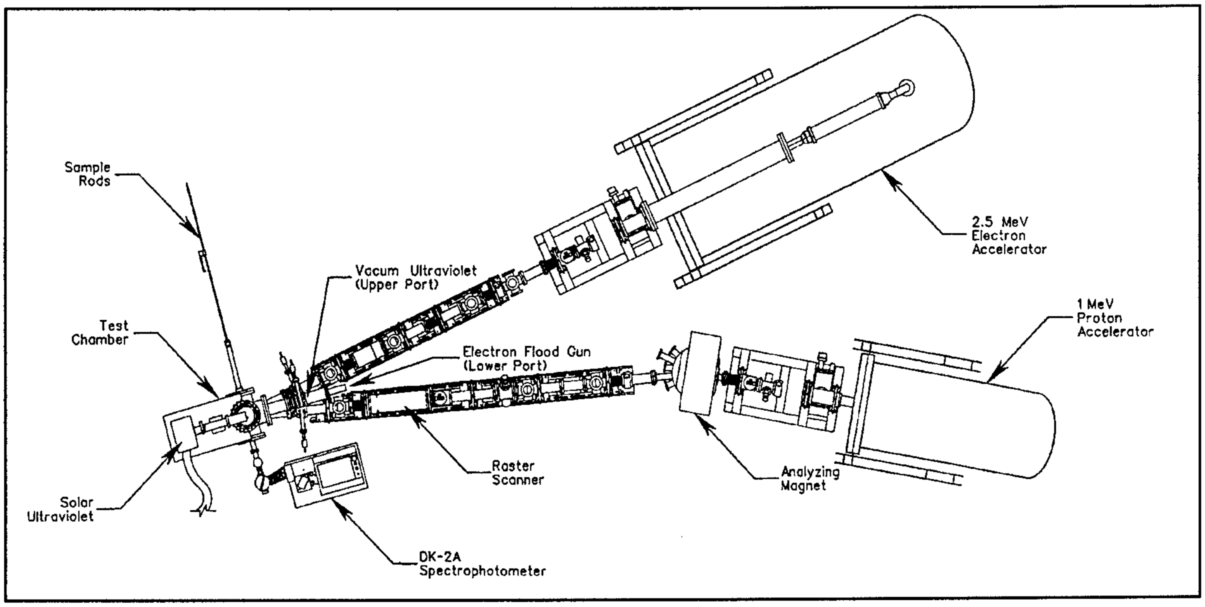



***Figure 3-5. Combined Environmental Effects Test-Cell 3***

The NUV source is external to the test chamber and produces photons over the range of 200 to 2,500 nm. This source can also produce ten times the sun's NUV radiation (250 to 400 nm) for accelerated testing.

The CEETC3 provides designers, engineers, and scientists with valuable information on the behavior of materials in a space environment. MSFC has used this facility to qualify materials for the space shuttle, ISS, and the Solar X-Ray Imager. The CEETC3 was also used in post-flight analysis of experiments, such as the Long Duration Exposure Facility (LDEF) which was exposed to a space environment for 5.5 years. Material samples from LDEF were then examined to determine the changes in optical, mechanical, and electrical properties. The synergistic effects of these property changes are still not completely understood, and continues to be investigated by space environmental effects testing facilities.

## Telemetry Processing Systems

MSFC's Huntsville Operations Support Center (HOSC) manages and processes telemetry data for payloads such as real-time operations of ISS. Payloads typically consist of multiple experiments. HOSC receives Ku-band and S-band telemetry data through the NASA Integrated Services Network, and sends commands, data loads, and file uplink data for the ISS payloads to the Space Station Control Center (SSCC). In return, SSCC sends command responses, downlink files, and planning data/procedures to HOSC. MSFC's support center can also distribute encapsulated packet data to other payload telemetry sites (e.g., international partners, telescience support centers, remote facilities).

HOSC is comprised of four systems:

- Payload Planning System — Provides a unique payload operations and integration architecture subsystem with software capabilities to automate payload planning and scheduling activities.
- Payload Data Services System — Acquires, distributes, and stores ISS data for other payload telemetry sites.
- Enhanced HOSC System — Performs on-command and real-time telemetry processing for prelaunch integration/checkout, simulations, training, and flight operations.
- Enhanced Mission Communications System

By processing telemetry data, HOSC enables users to operate and control ISS payloads and experiments. All users can access the support center's capabilities via a workstation as well as voice, video, and data network services. Remote users can access HOSC by logging on with a password through X-windows and web services.

## *Production*

### Friction Stir Welding

Friction stir welding is under development as an alternative to fusion welding. Improved mechanical properties (Figure 3-6) are inherent in this alternative process as fine grain microstructures comparable to ASTM No. 10, and tensile and elongation properties far exceed fusion weld practices. To date, the panel specimens have been comprised of aluminum alloys 2195 and 2219. In all cases, the welds generated had greater ductility and up to 50% less shrinkage than those produced by fusion welding.

Friction stir welding is a simplistic process that operates at low spindle speeds (300 to 400 rpm) without any filler materials or shielding gases, yet is capital intensive with tooling and equipment. The primary set up requires excessive use of clamping devices along either side of the weld spindle to offset distortions imparted by the high pressure (1,000 psi) needed to create plasticity at 800° F for metal flow. As the spindle head penetrates the work piece at four to five inches per minute, a patented pin tool descends to the workpiece at an angle of 2.5° away from the spindle's travel path. The weld penetration depth has been predetermined, but should not travel deeper than 0.005 inches from the opposite baseplate surface. Tooling is reusable and usually shows no discernible wear. To alleviate the pin retraction marks, MSFC developed and patented a retraction tool.

MSFC is currently conducting studies to determine the feasibility of using friction stir welding to manufacture hydrogen fuel tanks and as a replacement process for situations where current material join methods are mechanically inferior. The Center has already demonstrated the commercial use of friction stir welding for manufacturing aluminum 5454 wheel rims. Additional projects are underway including using this process to fabricate large circumferential (16-foot diameter) parts. Friction stir welding has already been perfected for other materials including copper and titanium. Additional information on these practices can be obtained through the original developer of friction stir welding, the Weld Institute in Cambridge, England.

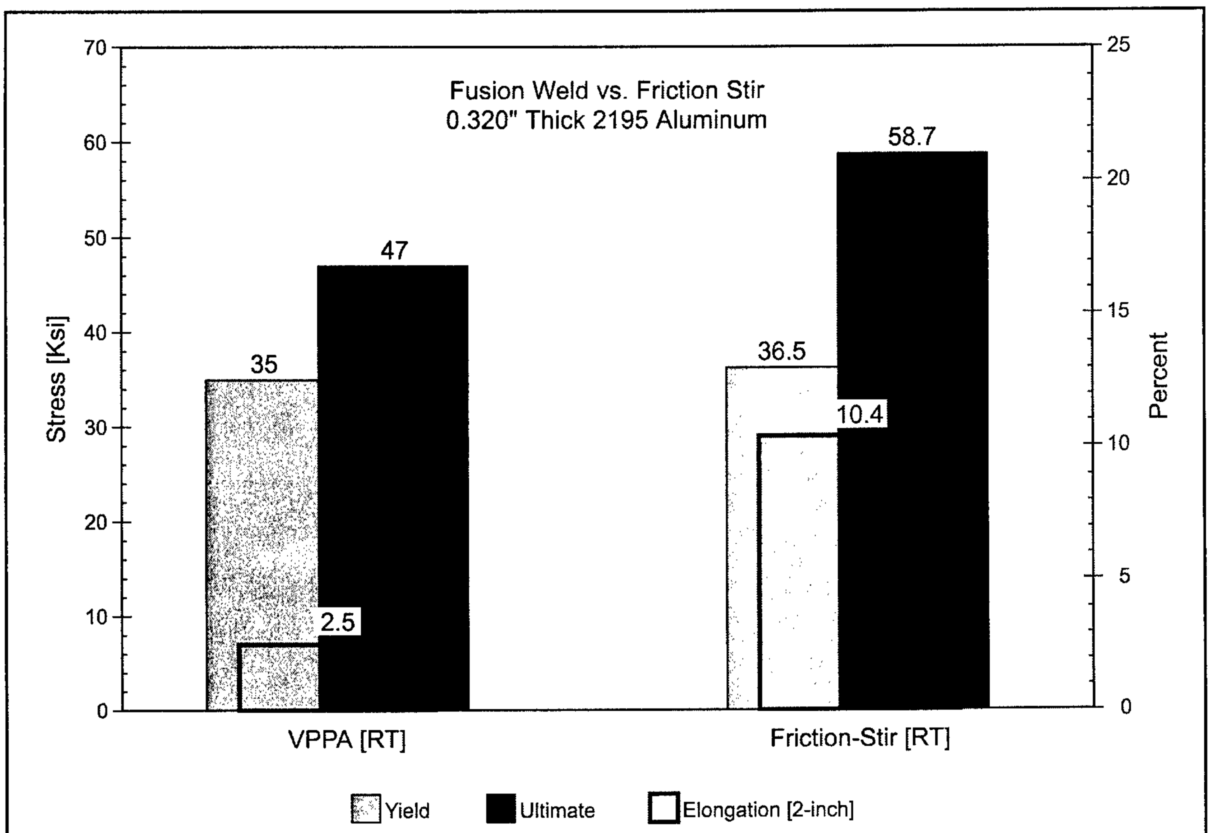



***Figure 3-6. Improved Mechanical Properties***

## Vacuum System Automation

MSFC's Environmental Test Facility (ETF) is currently implementing the Vacuum System Automation project. This project involves upgrading and automating the facility's 20 vacuum chambers. Automation will be controlled with Supervisory Control and Data Acquisition (SCADA) software, so operators can access the chambers via the Internet for data and via remote dial-ins for parameter adjustments.

The project is designed to expand ETF's operating efficiencies, especially during evenings and weekends. MSFC's goal is to have all chamber functions (e.g., chamber evacuation, re-pressurization, thermal conditioning, data retrieval) controlled through a computer. Each workstation will be capable of controlling any chamber and provide limited accessibility via remote control. Although the computing technologies (Windows NT 4.0 with networking TCP/IP) have COTS capabilities, the SCADA software is a licensed commercial product (by Fixed Dynamics) which costs about $6,000 per workstation. The ETF team is in the early stages of debugging the new software interface to the input/output hardware. This upgrade is expected to cost between $22,500 and $35,000 per chamber.

The Vacuum System Automation project is currently in its first year of a six to seven-year implementation cycle. Once the project is completed, MSFC expects to realize cost avoidance by not hiring new technicians and supervisors for night/weekend operations; decrease overtime through off-site monitoring; enable customer and management monitoring from remote computers; and reduce operator errors via computer monitoring and Graphical User Interfaces.

# *Facilities*

## Metallurgical Diagnostics Facility

Prior business practices at MSFC's Metallurgical Diagnostics Facility caused its work planning process to be labor intensive and cumbersome. Documentation of tasks was erratic and difficult to retrieve. Work requests could not be queried in support of new investigations. Photographic negatives were logged and stored in the areas associated with the equipment used to do the work. The system was highly dependent on the availability and recollections of individuals. Beginning in 1994, MSFC identified four areas in which to make improvements: (1) work request closure verification, (2) documentation and image storage and retrieval, (3) budget planning and justification, and (4) data access and distribution.

Consequently, MSFC formed a multi-discipline team to identify specific improvement issues and develop a long-term organizational and facility plan for implementation. By using various tools (e.g., Quality Function Deployment, brainstorming), the team also established a scope and format that focused on a failure analysis database; an electronic work request system; conversion from photographic to digital imaging; and the development of a branch web presence. All these objectives have now been implemented. The Facility's Failure Analysis Database is a cross-referenced tool that can be searched via keywords. Work requests, active tasks, and completed projects are set up as easily accessible, computer-based documentation. All imaging is now in a digital format and stored in the searchable Electronic Database. A website (http://eh22web.msfc.nasa.gov) has also been established for the Metallurgical Diagnostics Facility.

These advancements have eased MSFC's transition to ISO-9000 certification and to the recently implemented NASA Full Cost Accounting requirements. In addition, the Metallurgical Diagnostics Facility expanded its customer base to include other NASA enterprises, government agencies, universities, and industry.

## Plating Research Facility

MSFC's Plating Research Facility is currently developing a plating process which will allow multiple replicated optical mirrors to be produced from one mandrel. Once finalized, this process will be implemented in the Constellation X and Next Generation Space Telescope programs. The previous process involved multiple mandrels of the same shape and size on which the mirror material was plated and polished. The challenge for the Plating Research Facility is to develop the processing for space-based optical systems with much larger apertures and greater resolution, which does not require post-polishing.

The technical objective is to demonstrate a replicated optical systems manufacturing process that uses a single process flow: polish a single mandrel; apply electroless nickel-phosphorus; diamond turn and polish; apply gold coating; electroform nickel alloy shell; separate the shell; clean the mandrel; and repeat for next shell. Criteria for alloy selection include high specific strength, ultra-low durability, high elastic modulus, and the ability to maintain the optical figure without deformation. Technical prob-

lems encountered include the measurement of zero stress environment during plating, weight budget versus optical performance, and support structures needed to stabilize the shell.

MSFC's Plating Research Facility is well on its way to finalizing the process. The developers have learned to define and control multiple plating parameters including temperature, current density, component placement in tanks, bath chemistry and consumption rate, shielding, and fluid flow. The process is expected to help industry manufacture more accurate space telescopes.

## *Management*

### New Initiatives of NASA Acquisition Internet Service

The NASA Acquisition Internet Service (NAIS) is an agency-wide, on-line capability that communicates procurement information (e.g., synopsis information, advance procurement notices, contract award notices, solicitations, amendments) to industry. In an effort to continue improving NAIS, MSFC has embarked on several enhancements. Two such initiatives are the Procurement Data Warehouse System (PDWS) and the Request For Quotes System (RFQS).

PDWS is an effort to gather all the procurement data from each NASA Center, centrally located it on a NASA website, and make it available to procurement professionals. Previously, this information was stored in numerous databases among all the Centers. By using PDWS, contract specialists can search the vendor source database to obtain data on those firms that conduct business with NASA. In addition, this system provides NASA procurement management with metric data such as procurement productivity, contract status, and buyer productivity levels. The first phase of PDWS has recently been deployed to the workforce at MSFC.

RFQS allows vendors to submit on-line quotations to business solicitations. In addition, vendors who registered their business interests with NAIS will receive e-mail notification of upcoming opportunities. This system will reduce procurement paperwork and increase communication between NASA procurement professionals and industry. RFQS is in the pilot stage and has not yet been deployed.

MSFC continues to develop innovative ways for doing business. PDWS and RFQS represent the next phases of how NASA is improving its procurement process.

### Payload Safety Readiness Review Board

NASA's Enterprise Strategic Goals rank safety as a high priority in the exploration and development of space. Likewise, safety is an integral part of all MSFC programs and operations. Safety engineers actively participate in the design and development of payloads to ensure the safety of astronauts, ground personnel, launch vehicles, and other instrumentation. Hazard analyses are the primary tool in determining the safety level of payload designs and operations. Previously, projects submitted for phased safety panel reviews at NASA JSC were often subjected to hurriedly prepared dry-run presentations. Occasionally, the project team openly debated the design details at these reviews. The JSC Safety Panel perceived these discussions as a lack of knowledge on the team's behalf, and were concerned about the accuracy of the information being presented. This concern was reported back to MSFC as an unacceptable level of performance.

In July 1996, MSFC created an internal Payload Safety Readiness Review Board (PSRRB) to ensure the quality of its payload safety processes and products. Additionally, the Safety and Mission Assurance Office developed a Center Safety Readiness Review process to improve this aspect of work and provide a means of ensuring in-depth flight readiness of all payloads and experiments. Each PSRRB is chaired by a senior technical manager and utilizes members from appropriate engineering disciplines. The Board is responsible for issuing changes and makes the final decision for acceptance.

MSFC is using the PSRRB review process on a wide range of payloads and flight experiments, ranging from relatively simple microgravity experiments to highly complex systems such as the Chandra X-Ray Observatory. Keys to the success of this process are a high level of attention by management and the use of a formalized dry-run approach. Data captured between March 1995 and November 1998 indicates that the PSRRB review process has significantly improved the outcomes at the JSC Safety Review Panel. The number of unsigned hazard reports decreased from 31.7% to 15.7%, and the number of assigned action items dropped from 8.15 to 3.37 per review.

### Project Light

In the past, total quality management practices and quality circles were standard methods for implementing change at MSFC. However, downsizing,

budget reductions, and the need to develop more efficient work processes caused the Center to look for another approach. In 1996, MSFC implemented Project Light as a Center-wide program to bring about change and process improvement. The program's name is an acronym for:

- **L**isten to our customers
- **I**dentify where we need to change
- **G**uide our future
- **H**elp our team members
- **T**ransform our process

MSFC chose a quality action team approach as the methodology for Project Light. The program's structure consists of Cross-Functional Employee Teams (providers and customers from multiple organizational levels) and an Executive Steering Committee (three center managers, four functional managers, one program manager, two employees). The Teams identify issues, review processes for possible improvement, and make recommendations to the Executive Steering Committee. The Committee provides guidance to the Teams and can grant on-the-spot approval for a process change. Project Light debuted with 53 employees who met offsite to brainstorm ideas of improvement. As a result, 18 action teams were set up and 350 ideas were generated, categorized, and prioritized. Additional employees later joined these teams as supplemental resources were needed. To date, more than 250 employees, representing 10% of MSFC's workforce, have participated on these teams.

Changes implemented through Project Light fall into three categories: (1) Enhanced Communications, (2) Employee Development, and (3) Work Processes. Improvements for Enhanced Communications include *Inside MSFC*, an Intranet website that posts current events and vacancy announcements; IDEAs, an employee suggestion plan; and a new directorate that focuses on internal communication issues and community outreach. Improvements for Employee Development include core competencies for all positions; individual development plans; a pilot mentoring program to pass along corporate knowledge to new MSFC employees; a three-fold increase in the training budget; and an upgrade of secretarial positions to office managers which allows for pay increases and career advancement. Improvements for Work Processes include ISO-9000 project and a flexi-place pilot program.

MSFC's Project Light has been instrumental in bringing about effective changes to the organization. Constant communication throughout the Center greatly facilitates the improvement process. In addition, the structured team approach fosters innovative improvements as employees are now empowered to initiate change.

## Strategic and Implementation Planning

Enacted in 1993, the Government Performance and Results Act (GPRA) requires all federal agencies to develop strategic and performance plans which outline their goals and objectives in outcome-based terms. MSFC is complying with this act, and has implemented a strategic planning process that sets performance goals for the upcoming fiscal year and defines performance indicators to measure outcomes. Prior to FY98, no formal strategic planning activity existed.

MSFC receives its strategic direction from NASA Headquarters. In its Agency Strategic Plan, NASA identifies four Strategic Enterprises: (1) human exploration and development of space, (2) aerospace technology, (3) space science, and (4) earth science. Collectively, these enterprises drive NASA's Performance Plan, which is the strategic planning document that outlines short-term goals and objectives required to support the mission. In turn, each NASA Center develops an implementation plan that outlines the steps that their organization will take to enact these goals.

Through its strategic planning process, MSFC produces a Center Implementation Plan and a Performance Report. The Center Implementation Plan lists the steps that each MSFC program will undertake to support the NASA mission, and ensures a linkage between MSFC's activities and NASA's Strategic Enterprises. The plan is developed annually in early May, reviewed by the customer in mid-July, and distributed electronically in mid-August. The Center also uses a feedback loop to obtain input at the program level. The Performance Report summarizes the progress of each MSFC program, and evaluates them against performance indicators. A detailed review of these indicators are included in MSFC's Annual Report. This report is developed annually in early November and published in late March. MSFC communicates all strategic planning information to its employees. These documents are available for review on MSFC's website, and all employees receive a copy of the Center Implementation Plan.

MSFC's strategic planning process represents an organized approach to comply with GPRA requirements, and creates synergy throughout the Center. By showing employees how their efforts contribute to the NASA mission, MSFC ensures that all elements of the organization are familiar with the Center's strategic direction.

# Appendix A
## *Table of Acronyms*

| Acronym | Definition |
|---|---|
| 6DOF | Six-Degrees-Of-Freedom |
| ABMA | Army Ballistic Missile Agency |
| ANVIL | Army/NASA Virtual Innovations Laboratory |
| CAD | Computer Aided Design |
| CADDMAS | Computer Aided Dynamic Data Monitoring and Analysis System |
| CBD | Commerce Business Daily |
| CBM | Common Berthing Mechanism |
| CEC | Collaborative Engineering Center |
| CEETC3 | Combined Environmental Effects Test-Cell 3 |
| CER | Cost Estimating Relationship |
| CFD | Computational Fluid Dynamics |
| CMIF | Core Module Integration Facility |
| COTS | Commercial-Off-The-Shelf |
| CPCMS | Coherent Phase Cavitation Monitoring System |
| CST | Convergent Spray Technology |
| CT | Computed Tomography |
| ECLSS | Environmental Control and Life Support Systems |
| EMC | Electromagnetic Compatibility |
| EMI | Electromagnetic Interference |
| EOIM | Evaluation of Oxygen Interaction with Materials |
| ETF | Environmental Test Facility |
| FAR | Federal Acquisition Regulations |
| FEA | Finite Element Analysis |
| FESD | Functional Event Sequence Diagram |
| GDM | Gas Dynamic Mirror |
| GPRA | Government Performance and Results Act |
| HBS | Heatpipe Bimodal System |
| HOSC | Huntsville Operations Support Center |
| Hz | Hertz |
| IR | Infrared |
| ISEAS | Integrated Space Station Electromagnetic Compatibility Analysis System |
| ISS | International Space Station |
| JSC | Johnson Space Center |
| LDEF | Long Duration Exposure Facility |
| LH2 | Liquid Hydrogen |

| Acronym | Definition |
|---|---|
| MCC-1 | Marshall Convergent Coating-1 |
| MEDIC | Marshall Electromagnetic Compatibility Design and Interference Control |
| METRO | Marshall's ElecTRonic Office |
| MOL | Mission Operations Laboratory |
| MSA-2 | Marshall Sprayable Ablator-2 |
| MSFC | Marshall Space Flight Center |
| NAFCOM | NASA/Air Force Cost Model |
| NAIS | NASA Acquisition Internet Service |
| NASA | National Aeronautics and Space Administration |
| NUV | Near Ultraviolet |
| OASIS | Optimized Advanced System Integration and Simulation |
| OISPS | Operator Interactive Signal Processing System |
| OPAD | Optical Plume Anomaly Detection |
| PAMELA | Phased Array Mirror Extendible Large Aperture |
| PDS | Program/Project Data System |
| PDWS | Procurement Data Warehouse System |
| PEC | Productivity Enhancement Complex |
| PSRRB | Payload Safety Readiness Review Board |
| QRAS | Quantitative Risk Assessment System |
| REDSTAR | Resource Data Storage and Retrieval |
| RFQS | Request For Quotes System |
| RLV | Reusable Launch Vehicle |
| RP | Rapid Prototyping |
| SCADA | Supervisory Control and Data Acquisition |
| SLC | Space Leadership Council |
| SRB | Solid Rocket Booster |
| SSCC | Space Station Control Center |
| UUT | Unit Under Test |
| VUV | Vacuum Ultraviolet |
| XRCF | X-Ray Calibration Facility |

# Appendix B
## *BMP Survey Team*

| Team Member | Activity | Function |
|---|---|---|
| **Larry Robertson**<br>(812) 854-5336 | **Crane Division**<br>**Naval Surface Warfare Center**<br>Crane, IN | **Team Chairman** |
| **Cheri Spencer**<br>(301) 403-8100 | **BMP Center of Excellence**<br>College Park, MD | **Technical Writer** |
| | **Design/Test Team 1** | |
| **Nick Keller**<br>(812) 854-5331 | **Naval Surface Warfare Center**<br>Crane, IN | **Team Leader** |
| **Michael Ripp**<br>(909) 273-4939 | **Naval Warfare Assessment Station**<br>Corona, CA | |
| **Huston Singletary**<br>(423) 574-6394 | **Lockheed Martin Energy Systems**<br>Oak Ridge, TN | |
| | **Design/Test Team 2** | |
| **Ron Cox**<br>(812) 854-5330 | **Naval Surface Warfare Center**<br>Crane, IN | **Team Leader** |
| **John Suhan**<br>(814) 865-7223 | **Applied Research Laboratory,**<br>**Penn State**<br>State College, PA | |
| **Nicholas Clarke Pente**<br>(909) 273-4990 | **Naval Warfare Assessment Station**<br>Corona, CA | |
| | **Production/Facilities Team** | |
| **Darrel Brotherson**<br>(319) 295-3768 | **Rockwell Collins**<br>**Avionics & Communications**<br>Cedar Rapids, IA | **Team Leader** |
| **Jack Tamargo**<br>(707) 642-4267 | **BMP Satellite Center**<br>Vallejo, CA | |

| | | |
|---|---|---|
| **David Snow**<br>(317) 635-3058 | **Indiana Business**<br>**Modernization & Technology**<br>Indianapolis, IN | |

### Management/Logistics Team

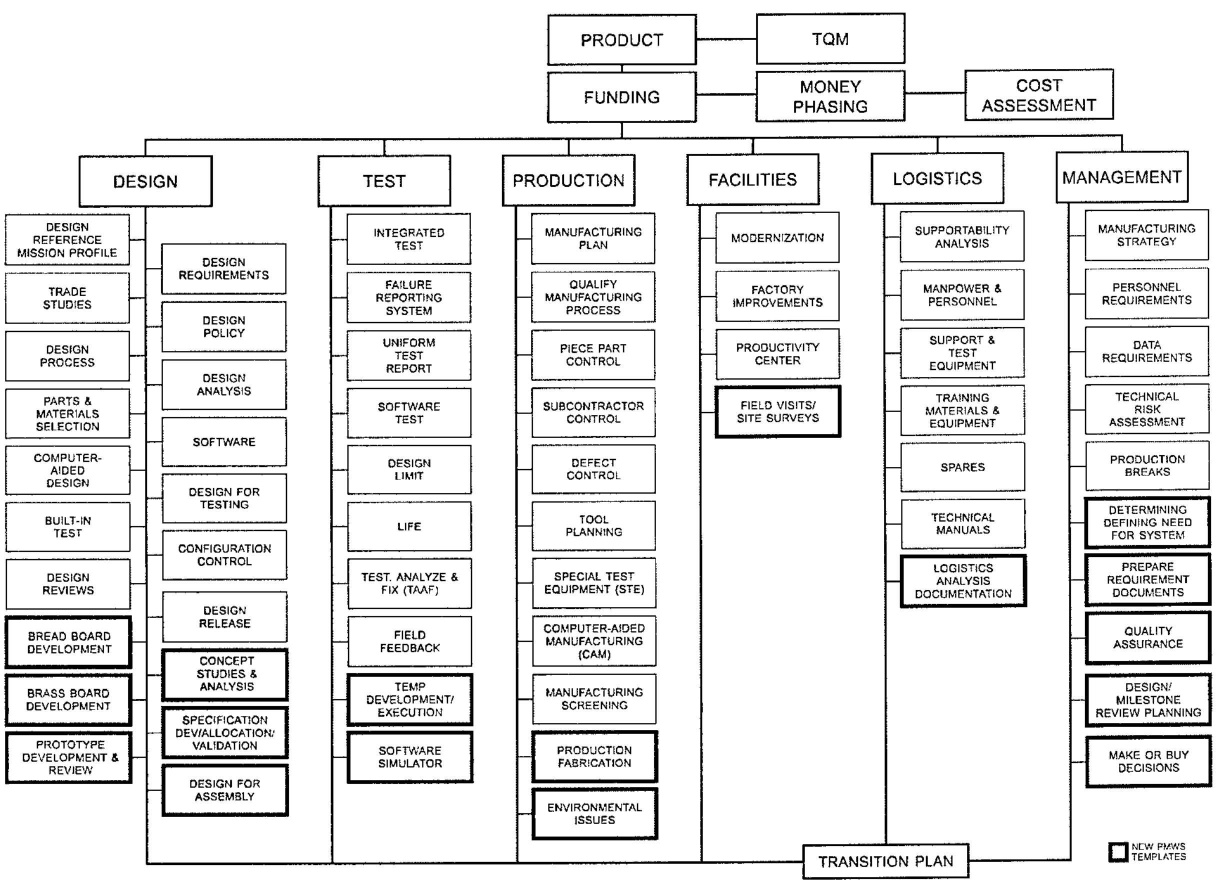
| | | |
|---|---|---|
| **Rick Purcell**<br>(301) 403-8100 | **BMP Center of Excellence**<br>College Park, MD | **Team Leader** |
| **Larry Halbig**<br>(317) 891-9901 | **BMP Field Office**<br>Indianapolis, IN | |
| **Stephanie Shattuck**<br>(703) 808-6928 | **NRO, Acquisition Center of Excellence**<br>Chantilly, VA | |

# Appendix C
## *Critical Path Templates and BMP Templates*

This survey was structured around and concentrated on the functional areas of design, test, production, facilities, logistics, and management as presented in the Department of Defense 4245.7-M, *Transition from Development to Production* document. This publication defines the proper tools—or templates—that constitute the critical path for a successful material acquisition program. It describes techniques for improving the acquisition process by addressing it as an *industrial* process that focuses on the product's design, test, and production phases which are interrelated and interdependent disciplines.

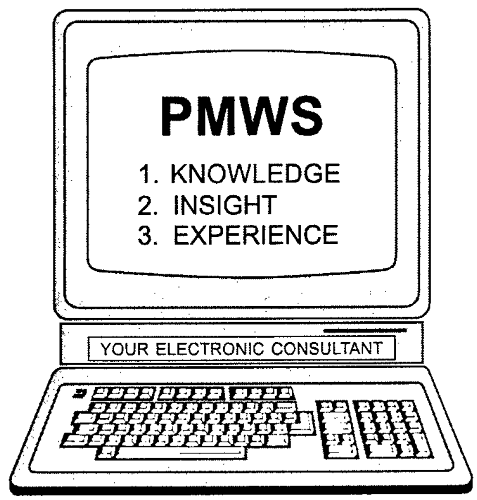
The BMP program has continued to build on this knowledge base by developing 17 new templates that complement the existing DOD 4245.7-M templates. These BMP templates address new or emerging technologies and processes.

## "CRITICAL PATH TEMPLATES FOR TRANSITION FROM DEVELOPMENT TO PRODUCTION"



# Appendix D
## *BMPnet and the Program Manager's WorkStation*

The BMPnet, located at the Best Manufacturing Practices Center of Excellence (BMPCOE) in College Park, Maryland, supports several communication features. These features include the Program Manager's WorkStation (**PMWS**), electronic mail and file transfer capabilities, as well as access to Special Interest Groups (SIGs) for specific topic information and communication. The BMPnet can be accessed through the World Wide Web (at http://www.bmpcoe.org), through free software that connects directly over the Internet or through a modem. The PMWS software is also available on CD-ROM.




PMWS provides users with timely acquisition and engineering information through a series of interrelated software environments and knowledge-based packages. The main components of PMWS are KnowHow, SpecRite, the Technical Risk Identification and Mitigation System (TRIMS), and the BMP Database.

**KnowHow** is an intelligent, automated program that provides rapid access to information through an intelligent search capability. Information currently available in KnowHow handbooks includes Acquisition Streamlining, Non-Development Items, Value Engineering, NAVSO P-6071 (Best Practices Manual), MIL-STD-2167/2168 and the DoD 5000 series documents. KnowHow cuts document search time by 95%, providing critical, user-specific information in under three minutes.

**SpecRite** is a performance specification generator based on expert knowledge from all uniformed services. This program guides acquisition personnel in creating specifications for their requirements, and is structured for the build/approval process. SpecRite's knowledge-based guidance and assistance structure is modular, flexible, and provides output in MIL-STD 961D format in the form of editable WordPerfect® files.

**TRIMS**, based on DoD 4245.7-M (the transition templates), NAVSO P-6071, and DoD 5000 event-oriented acquisition, helps the user identify and rank a program's high-risk areas. By helping the user conduct a full range of risk assessments throughout the acquisition process, TRIMS highlights areas where corrective action can be initiated before risks develop into problems. It also helps users track key project documentation from concept through production including goals, responsible personnel, and next action dates for future activities.

The **BMP Database** con-tains proven best practices from industry, government, and the academic communities. These best practices are in the areas of design, test, production, facilities, management, and logistics. Each practice has been observed, verified, and documented by a team of government experts during BMP surveys.

Access to the BMPnet through dial-in or on Internet requires a special modem program. This program can be obtained by calling the BMPnet Help Desk at (301) 403-8179 or it can be downloaded from the World Wide Web at http://www.bmpcoe.org. To receive a user/e-mail account on the BMPnet, send a request to helpdesk@bmpcoe.org.

# Appendix E

## *Best Manufacturing Practices Satellite Centers*

There are currently ten Best Manufacturing Practices (BMP) satellite centers that provide representation for and awareness of the BMP program to regional industry, government and academic institutions. The centers also promote the use of BMP with regional Manufacturing Technology Centers. Regional manufacturers can take advantage of the BMP satellite centers to help resolve problems, as the centers host informative, one-day regional workshops that focus on specific technical issues.

Center representatives also conduct BMP lectures at regional colleges and universities; maintain lists of experts who are potential survey team members; provide team member training; and train regional personnel in the use of BMP resources such as the BMPnet.

The ten BMP satellite centers include:

<u>California</u>

**Chris Matzke**
BMP Satellite Center Manager
Naval Warfare Assessment Division
Code QA-21, P.O. Box 5000
Corona, CA 91718-5000
(909) 273-4992
FAX: (909) 273-4123
cmatzke@bmpcoe.org

**Jack Tamargo**
BMP Satellite Center Manager
257 Cottonwood Drive
Vallejo, CA 94591
(707) 642-4267
FAX: (707) 642-4267
jtamargo@bmpcoe.org

<u>District of Columbia</u>

**Chris Weller**
BMP Satellite Center Manager
U.S. Department of Commerce
14th Street & Constitution Avenue, NW
Room 3876 BXA
Washington, DC 20230
(202) 482-8236/3795
FAX: (202) 482-5650
cweller@bxa.doc.gov

<u>Illinois</u>

**Thomas Clark**
BMP Satellite Center Manager
Rock Valley College
3301 North Mulford Road
Rockford, IL 61114
(815) 654-5515
FAX: (815) 654-4459
adme3tc@rvcux1.rvc.cc.il.us

<u>Iowa</u>

**Bruce Coney**
Program Manager
Iowa Procurement Outreach Center
200 East Grand Avenue
Des Moines, IA 50309
(515) 242-4888
FAX: (515) 242-4893
bruce.coney@ided.state.ia.us

<u>Louisiana</u>

**Al Knecht**
Director
Maritime Environmental Resources & Information Center
Gulf Coast Region Maritime Technology Center
University of New Orleans
810 Engineering Building
New Orleans, LA 70148
(504) 626-8918 / (504) 280-6271
FAX: (504) 727-4121
atk@neosoft.com

<u>Michigan</u>

**Jack Pokrzywa**
SAE/BMP Satellite Center Manager
755 W. Big Beaver Road, Suite 1600
Troy, MI 48084
(248) 273-2460
FAX: (248) 273-2494
jackp@sae.org

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Ohio

**Karen Malone**
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Pennsylvania

**Sherrie Snyder**
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Tennessee

**Tammy Graham**
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Lockheed Martin Energy Systems
P.O. Box 2009, Bldg. 9737
M/S 8091
Oak Ridge, TN 37831-8091
(423) 576-5532
FAX: (423) 574-2000
tgraham@bmpcoe.org

# Appendix F
## *Navy Manufacturing Technology Centers of Excellence*

The Navy Manufacturing Sciences and Technology Program established the following Centers of Excellence (COEs) to provide focal points for the development and technology transfer of new manufacturing processes and equipment in a cooperative environment with industry, academia, and Navy centers and laboratories. These COEs are consortium-structured for industry, academia, and government involvement in developing and implementing technologies. Each COE has a designated point of contact listed below with the individual COE information.

### Best Manufacturing Practices Center of Excellence

The Best Manufacturing Practices Center of Excellence (BMPCOE) provides a national resource to identify and promote exemplary manufacturing and business practices and to disseminate this information to the U.S. Industrial Base. The BMPCOE was established by the Navy's BMP program, Department of Commerce's National Institute of Standards and Technology, and the University of Maryland at College Park, Maryland. The BMPCOE improves the use of existing technology, promotes the introduction of improved technologies, and provides non-competitive means to address common problems, and has become a significant factor in countering foreign competition.

Point of Contact:
Mr. Ernie Renner
Best Manufacturing Practices Center of Excellence
4321 Hartwick Road
Suite 400
College Park, MD 20740
(301) 403-8100
FAX: (301) 403-8180
ernie@bmpcoe.org

### Center of Excellence for Composites Manufacturing Technology

The Center of Excellence for Composites Manufacturing Technology (CECMT) provides a national resource for the development and dissemination of composites manufacturing technology to defense contractors and subcontractors. The CECMT is managed by the Great Lakes Composites Consortium and represents a collaborative effort among industry, academia, and government to develop, evaluate, demonstrate, and test composites manufacturing technologies. The technical work is problem-driven to reflect current and future Navy needs in the composites industrial community.

Point of Contact:
Mr. James Ray
Center of Excellence for Composites Manufacturing Technology
c/o GLCC, Inc.
103 Trade Zone Drive
Suite 26C
West Columbia, SC 29170
(803) 822-3708
FAX: (803) 822-3710
jrglcc@glcc.org

### Electronics Manufacturing Productivity Facility

The Electronics Manufacturing Productivity Facility (EMPF) identifies, develops, and transfers innovative electronics manufacturing processes to domestic firms in support of the manufacture of affordable military systems. The EMPF operates as a consortium comprised of industry, university, and government participants, led by the American Competitiveness Institute under a CRADA with the Navy.

Point of Contact:
Mr. Alan Criswell
Electronics Manufacturing Productivity Facility
One International Plaza
Suite 600
Philadelphia, PA 19113
(610) 362-1200
FAX: (610) 362-1290
criswell@aci-corp.org

### National Center for Excellence in Metalworking Technology

The National Center for Excellence in Metalworking Technology (NCEMT) provides a national center for the development, dissemination, and implemen-tation of advanced technologies for metalworking products and processes. The NCEMT, operated by Concurrent Technologies Corporation, helps the Navy and defense contractors improve manufacturing productivity and

part reliability through development, deployment, training, and education for advanced metalworking technologies.

Point of Contact:
Mr. Richard Henry
National Center for Excellence in Metalworking Technology
c/o Concurrent Technologies Corporation
100 CTC Drive
Johnstown, PA 15904-3374
(814) 269-2532
FAX: (814) 269-2501
henry@ctc.com

### Navy Joining Center

The Navy Joining Center (NJC) is operated by the Edison Welding Institute and provides a national resource for the development of materials joining expertise and the deployment of emerging manufacturing technologies to Navy contractors, subcontractors, and other activities. The NJC works with the Navy to determine and evaluate joining technology requirements and conduct technology development and deployment projects to address these issues.

Point of Contact:
Mr. David P. Edmonds
Navy Joining Center
1250 Arthur E. Adams Drive
Columbus, OH 43221-3585
(614) 688-5096
FAX: (614) 688-5001
dave_edmonds@ewi.org

### Energetics Manufacturing Technology Center

The Energetics Manufacturing Technology Center (EMTC) addresses unique manufacturing processes and problems of the energetics industrial base to ensure the availability of affordable, quality, and safe energetics. The focus of the EMTC is on process technology with a goal of reducing manufacturing costs while improving product quality and reliability. The EMTC also maintains a goal of development and implementation of environmentally benign energetics manufacturing processes.

Point of Contact:
Mr. John Brough
Energetics Manufacturing Technology Center
Indian Head Division
Naval Surface Warfare Center
101 Strauss Avenue
Building D326, Room 227
Indian Head, MD 20640-5035
(301) 744-4417
DSN: 354-4417
FAX: (301) 744-4187
mt@command.ih.navy.mil

### Institute for Manufacturing and Sustainment Technologies

The Institute for Manufacturing and Sustainment Technologies (iMAST), was formerly known as Manufacturing Science and Advanced Materials Processing Institute. Located at the Pennsylvania State University's Applied Research Labortory, the primary objective of iMAST is to address challenges relative to Navy and Marine Corps weapon system platforms in the areas of mechnical drive transmission techologies, materials science technologies, high energy processing technologies, and repair technology.

Point of Contact:
Mr. Henry Watson
Institute for Manufacturing and Sustainment Technologies
ARL Penn State
P.O. Box 30
State College, PA 16804-0030
(814) 865-6345
FAX: (814) 863-1183
hew2@psu.edu

## National Network for Electro-Optics Manufacturing Technology

The National Netowork for Electro-Optics Manufacturing Technology (NNEOMT), a low overhead virtual organization, is a national consortium of electro-optics industrial companies, universities, and government research centers that share their electro-optics expertise and capabilities through project teams focused on Navy requirements. NNEOMT is managed by the Ben Franklin Technology Center of Western Pennsylvania.

Point of Contact:
Dr. Raymond V. Wick
National Network for Electro-Optics Manufacturing Technology
One Parks Bend
Box 24, Suite 206
Vandergrift, PA 15690
(724) 845-1138
FAX: (724) 845-2448
wick@nneomt.org

## Gulf Coast Region Maritime Technology Center

The Gulf Coast Region Maritime Technology Center (GCRMTC) is located at the University of New Orleans and focuses primarily on product developments in support of the U.S. shipbuilding industry. A sister site at Lamar University in Orange, Texas focuses on process improvements.

Point of Contact:
Dr. John Crisp, P.E.
Gulf Coast Region Maritime Technology Center
University of New Orleans
College of Engineering
Room EN-212
New Orleans, LA 70148
(504) 280-5586
FAX: (504) 280-3898
jncme@uno.edu

## Manufacturing Technology Transfer Center

The focus of the Manufacturing Technology Transfer Center (MTTC) is to implement and integrate defense and commercial technologies and develop a technical assistance network to support the Dual Use Applications Program. MTTC is operated by Innovative Productivity, Inc., in partnership with industry, government, and academia.

Point of Contact:
Mr. Raymond Zavada
Manufacturing Technology Transfer Center
119 Rochester Drive
Louisville, KY 40214-2684
(502) 452-1131
FAX: (502) 451-9665
rzavada@mttc.org

# Appendix G
## *Completed Surveys*

As of this publication, 117 surveys have been conducted and published by BMP at the companies listed below. Copies of older survey reports may be obtained through DTIC or by accessing the BMPnet. Requests for copies of recent survey reports or inquiries regarding the BMPnet may be directed to:


Best Manufacturing Practices Program
4321 Hartwick Rd., Suite 400
College Park, MD 20740
Attn: Mr. Ernie Renner, Director
Telephone: 1-800-789-4267
FAX: (301) 403-8180
ernie@bmpcoe.org


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|---|---|
| **1985** | Litton Guidance & Control Systems Division - Woodland Hills, CA |
| **1986** | Honeywell, Incorporated Undersea Systems Division - Hopkins, MN (Alliant TechSystems, Inc.)<br>Texas Instruments Defense Systems & Electronics Group - Lewisville, TX<br>General Dynamics Pomona Division - Pomona, CA<br>Harris Corporation Government Support Systems Division - Syosset, NY<br>IBM Corporation Federal Systems Division - Owego, NY<br>Control Data Corporation Government Systems Division - Minneapolis, MN |
| **1987** | Hughes Aircraft Company Radar Systems Group - Los Angeles, CA<br>ITT Avionics Division - Clifton, NJ<br>Rockwell International Corporation Collins Defense Communications - Cedar Rapids, IA<br>UNISYS Computer Systems Division - St. Paul, MN (Paramax) |
| **1988** | Motorola Government Electronics Group - Scottsdale, AZ<br>General Dynamics Fort Worth Division - Fort Worth, TX<br>Texas Instruments Defense Systems & Electronics Group - Dallas, TX<br>Hughes Aircraft Company Missile Systems Group - Tucson, AZ<br>Bell Helicopter Textron, Inc. - Fort Worth, TX<br>Litton Data Systems Division - Van Nuys, CA<br>GTE $C^3$ Systems Sector - Needham Heights, MA |
| **1989** | McDonnell-Douglas Corporation McDonnell Aircraft Company - St. Louis, MO<br>Northrop Corporation Aircraft Division - Hawthorne, CA<br>Litton Applied Technology Division - San Jose, CA<br>Litton Amecom Division - College Park, MD<br>Standard Industries - LaMirada, CA<br>Engineered Circuit Research, Incorporated - Milpitas, CA<br>Teledyne Industries Incorporated Electronics Division - Newbury Park, CA<br>Lockheed Aeronautical Systems Company - Marietta, GA<br>Lockheed Corporation Missile Systems Division - Sunnyvale, CA<br>Westinghouse Electronic Systems Group - Baltimore, MD<br>General Electric Naval & Drive Turbine Systems - Fitchburg, MA<br>Rockwell International Corporation Autonetics Electronics Systems - Anaheim, CA<br>TRICOR Systems, Incorporated - Elgin, IL |
| **1990** | Hughes Aircraft Company Ground Systems Group - Fullerton, CA<br>TRW Military Electronics and Avionics Division - San Diego, CA<br>MechTronics of Arizona, Inc. - Phoenix, AZ<br>Boeing Aerospace & Electronics - Corinth, TX<br>Technology Matrix Consortium - Traverse City, MI<br>Textron Lycoming - Stratford, CT |

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| **1991** | *Resurvey of Litton Guidance & Control Systems Division* - Woodland Hills, CA<br>Norden Systems, Inc. - Norwalk, CT<br>Naval Avionics Center - Indianapolis, IN<br>United Electric Controls - Watertown, MA<br>Kurt Manufacturing Co. - Minneapolis, MN<br>MagneTek Defense Systems - Anaheim, CA<br>Raytheon Missile Systems Division - Andover, MA<br>AT&T Federal Systems Advanced Technologies and AT&T Bell Laboratories - Greensboro, NC and Whippany, NJ<br>*Resurvey of Texas Instruments Defense Systems & Electronics Group* - Lewisville, TX |
| **1992** | Tandem Computers - Cupertino, CA<br>Charleston Naval Shipyard - Charleston, SC<br>Conax Florida Corporation - St. Petersburg, FL<br>Texas Instruments Semiconductor Group Military Products - Midland, TX<br>Hewlett-Packard Palo Alto Fabrication Center - Palo Alto, CA<br>Watervliet U.S. Army Arsenal - Watervliet, NY<br>Digital Equipment Company Enclosures Business - Westfield, MA and Maynard, MA<br>Computing Devices International - Minneapolis, MN<br>*(Resurvey of Control Data Corporation Government Systems Division)*<br>Naval Aviation Depot Naval Air Station - Pensacola, FL |
| **1993** | NASA Marshall Space Flight Center - Huntsville, AL<br>Naval Aviation Depot Naval Air Station - Jacksonville, FL<br>Department of Energy Oak Ridge Facilities (Operated by Martin Marietta Energy Systems, Inc.) - Oak Ridge, TN<br>McDonnell Douglas Aerospace - Huntington Beach, CA<br>Crane Division Naval Surface Warfare Center - Crane, IN and Louisville, KY<br>Philadelphia Naval Shipyard - Philadelphia, PA<br>R. J. Reynolds Tobacco Company - Winston-Salem, NC<br>Crystal Gateway Marriott Hotel - Arlington, VA<br>Hamilton Standard Electronic Manufacturing Facility - Farmington, CT<br>Alpha Industries, Inc. - Methuen, MA |
| **1994** | Harris Semiconductor - Melbourne, FL<br>United Defense, L.P. Ground Systems Division - San Jose, CA<br>Naval Undersea Warfare Center Division Keyport - Keyport, WA<br>Mason & Hanger - Silas Mason Co., Inc. - Middletown, IA<br>Kaiser Electronics - San Jose, CA<br>U.S. Army Combat Systems Test Activity - Aberdeen, MD<br>Stafford County Public Schools - Stafford County, VA |
| **1995** | Sandia National Laboratories - Albuquerque, NM<br>Rockwell Defense Electronics Collins Avionics & Communications Division - Cedar Rapids, IA<br>*(Resurvey of Rockwell International Corporation Collins Defense Communications)*<br>Lockheed Martin Electronics & Missiles - Orlando, FL<br>McDonnell Douglas Aerospace (St. Louis) - St. Louis, MO<br>*(Resurvey of McDonnell-Douglas Corporation McDonnell Aircraft Company)*<br>Dayton Parts, Inc. - Harrisburg, PA<br>Wainwright Industries - St. Peters, MO<br>Lockheed Martin Tactical Aircraft Systems - Fort Worth, TX<br>*(Resurvey of General Dynamics Fort Worth Division)*<br>Lockheed Martin Government Electronic Systems - Moorestown, NJ<br>Sacramento Manufacturing and Services Division - Sacramento, CA<br>JLG Industries, Inc. - McConnellsburg, PA |
| **1996** | City of Chattanooga - Chattanooga, TN<br>Mason & Hanger Corporation - Pantex Plant - Amarillo, TX<br>Nascote Industries, Inc. - Nashville, IL<br>Weirton Steel Corporation - Weirton, WV<br>NASA Kennedy Space Center - Cape Canaveral, FL<br>Department of Energy, Oak Ridge Operations - Oak Ridge, TN |

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| **1997** | Headquarters, U.S. Army Industrial Operations Command - Rock Island, IL<br>SAE International and Performance Review Institute - Warrendale, PA<br>Polaroid Corporation - Waltham, MA<br>Cincinnati Milacron, Inc. - Cincinnati, OH<br>Lawrence Livermore National Laboratory - Livermore, CA<br>Sharretts Plating Company, Inc. - Emigsville, PA<br>Thermacore, Inc. - Lancaster, PA<br>Rock Island Arsenal - Rock Island, IL<br>Northrop Grumman Corporation - El Segundo, CA<br>*(Resurvey of Northrop Corporation Aircraft Division)*<br>Letterkenny Army Depot - Chambersburg, PA<br>Elizabethtown College - Elizabethtown, PA<br>Tooele Army Depot - Tooele, UT |
| **1998** | United Electric Controls - Watertown, MA<br>Strite Industries Limited - Cambridge, Ontario, Canada<br>Northrop Grumman Corporation - El Segundo, CA<br>Corpus Christi Army Depot - Corpus Christi, TX<br>Anniston Army Depot - Anniston, AL<br>Naval Air Warfare Center, Lakehurst - Lakehurst, NJ<br>Sierra Army Depot - Herlong, CA<br>ITT Industries Aerospace/Communications Division - Fort Wayne, IN<br>Raytheon Missile Systems Company - Tucson, AZ<br>Naval Aviation Depot North Island - San Diego, CA<br>*U.S.S. Carl Vinson* (CVN-70) - Commander Naval Air Force, U.S. Pacific Fleet<br>Tobyhanna Army Depot - Tobyhanna, PA |
| **1999** | Wilton Armetale - Mount Joy, PA<br>Applied Research Laboratory, Pennsylvania State University - State College, PA<br>Electric Boat Corporation, Quonset Point Facility - North Kingston, RI<br>NASA Marshall Space Flight Center - Huntsville, AL |